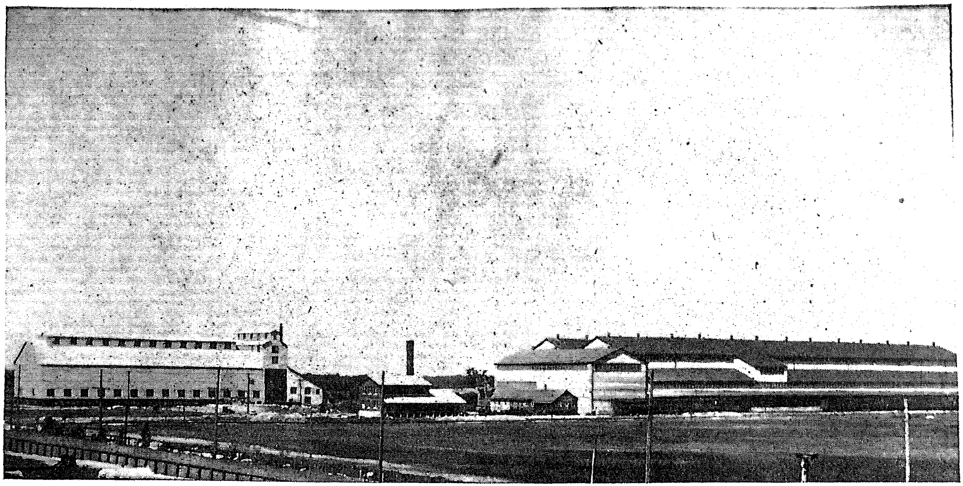
HANDBOOK OF FERTILIZERS



COMMERCIAL FERTILIZER FACTORY
(*Courtesy, Armour Fertilizer Works*).

Handbook of
FERTILIZERS

THEIR SOURCES, MAKE-UP, EFFECTS, AND USE

BY

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ILLUSTRATED

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PREFACE

SUCCESSFUL present-day farming and gardening require careful study, full information, and keen judgment at every point. In no phase of agriculture is there greater need for accurate information than concerning fertilizers and lime. This book is an attempt to supply accurate, up-to-date information as to the source and make-up of commercial fertilizers. Special stress is laid on the effects of fertilizers on soils and crops in the hope of aiding the user in making a wise choice for his individual soil and cropping conditions. A fertilizer should satisfy the requirements of the particular crop to be grown. Farmers are urged to consider the interrelationship between crops and the effects of the residues from fertilizers used for one crop on those which follow.

An effort is made to present information that will be helpful to home gardeners during the present war emergency and as well for a period following the return of peace. Because food prices may be high in comparison with the buying power of stationary incomes, the production of food in home gardens will be a necessity for many families.

Credit for illustrations is given in connection with them. This manuscript has been read and valuable suggestions made by several present and former co-workers. The writer desires to express to all of them his keen appreciation of the aid they have so generously given.

A. F. GUSTAFSON.

Ithaca, New York.
January, 1944

CONTENTS

ILLUSTRATIONS

Handbook of Fertilizers

I

REQUIREMENTS FOR PLANT GROWTH

For well-balanced normal growth and proper development plants need (1) water, (2) air, (3) light, (4) a favorable temperature, (5) sufficient root space and physical support, (6) proper drainage and physical condition, or suitable tilth of the soil, and (7) plant nutrients.

Some of these factors are under the control of man, but others are not. With air, light, and physical support we need have little concern, and we possess little control over temperature. Water comes to the soil as rain or snow, and man may influence in various ways the supply of it available for crops. He may plant tobacco, corn, cotton, potatoes, vegetables, and other clean-tilled crops up and down hill which often leads to the direct loss of much water and soil as well. On the other hand, he may practice contour plowing, that is, plowing across, and not up and down the principal slope. In addition, conducting other tillage operations on the contour and seeding close-growing crops such as wheat, alfalfa, clover, lespedeza, timothy, and all other hay

and grain crops across the slopes holds and conserves much water and soil for future use. Cultivation and other tillage operations reduce the evaporation of water from the soil during dry periods. Moreover, excess water may be removed from the soil by drainage and water may be added to soils by means of irrigation.

Man is directly responsible for maintaining suitable tilth for plants. This is accomplished through plowing, seed-bed preparation, cultivation, and by maintaining a goodly supply of organic matter in the soil. With the supply of plant nutrients as well, man is deeply concerned. He may allow crops to depend wholly on the soil for sustenance, or he may add plant nutrients in such materials as farm manures, fertilizers, and green manures.

ELEMENTS REQUIRED FOR THE GROWTH OF PLANTS

For many years botanists and plant chemists believed that only ten chemical elements [1] were needed for the growth of plants. Recently, however, it has been learned that at least four additional elements are absolutely necessary for normal plant growth.

[1] An element is a simple substance possessing certain definite properties. It cannot be separated into other substances by ordinary chemical means. Iron is a familiar example of an element.

ELEMENTS NEEDED FOR PLANT GROWTH

Element	*Chemical symbol*[2]	*Element*	*Chemical symbol*[2]
Nitrogen	N	Boron	B
Phosphorus	P	Sulfur	S
Potassium	K	Zinc	Zn
Calcium	Ca	Copper	Cu
Magnesium	Mg	Hydrogen	H
Iron	Fe	Oxygen	O
Manganese	Mn	Carbon	C

Manganese, copper, boron, and zinc have been found during comparatively recent years to be essential for plant growth. These elements are present in most, if not all, soils, but other elements or some abnormal soil condition may prevent the plant from using them. Consequently the plant suffers the same as if these elements were not present in the soil. Iodine and sodium are often helpful to plants but plant scientists do not generally accept this evidence as conclusive that either iodine or sodium is absolutely essential for plant growth. Chlorine and silicon which some had believed to be essential are not so regarded now. As methods of chemical analysis are refined, however, it appears probable that additional elements may prove to be equally as necessary for plant growth as are any of the fourteen elements listed here.

How Plants Obtain Nutrients—Plants obtain

[2] Symbols are used like abbreviations as a matter of convenience. Just as it is easier and quicker to write Pa. instead of Pennsylvania, the chemist uses P instead of phosphorus or K for potassium.

oxygen, hydrogen, carbon, and nitrogen from water and the air. Nitrogen from the air is used only by legume plants through the aid of bacteria working in the nodules on their roots. Carbon and oxygen from the air enter the leaves as carbon dioxide (CO_2), which is produced in the decay and burning of organic matter and coal, in many simple chemical reactions, and in many of the important life processes of animals. Hydrogen comes largely, if not wholly, from water. Nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, sulfur, zinc, and copper are obtained by plants through their roots from the soil. Although the mineral elements are all-important in the growth of plants, they constitute only a very small percentage of their entire weight. This may be easily appreciated when we consider how little ash remains after wood or other plant material is burned. The ash, which contains all of the mineral material used by the plant in its development, constitutes from one-half to two and one-half per cent of the weight of green plants. In general, plants obtain all of the carbon, oxygen, and hydrogen needed for complete development, except hydrogen during drought. Usually it is the lack of nitrogen or of one or more of the mineral elements, that limits crop growth. The term *limiting element* is applied to a nutrient which is absent or which for any reason is unavailable and as a consequence limits the growth of crops.

FERTILIZER ELEMENTS

Nitrogen, phosphorus, and potassium are regarded as the more important fertilizer elements, since it is one or more of these which most often controls or limits the yield of crops. They may limit crop yields because they are really lacking, or because they occur in insoluble material from which the crop cannot obtain the supply of them needed for good growth. In addition calcium, magnesium, manganese, sulfur, and much less frequently zinc, copper, boron, and iron may not be present in available form or in sufficient quantities for well-balanced normal growth.

Nitrogen—Nitrogen makes up nearly four-fifths of the air, so there is no shortage of this necessary nutrient element. This being true, why has nitrogen been expensive in mixed fertilizers? Nitrogen is inactive but elusive. Most of our crops can use nitrogen only when it is combined with other elements. Of combined nitrogen the supply is limited and this accounts for its relatively high cost. Fortunately for mankind legumes, when properly inoculated, through a close relationship with bacteria working in the nodules on their roots, take nitrogen from the air and use it in their growth. Among the more commonly known garden and farm-crop legumes are beans and peas and clovers and alfalfa. All other families of plants may be classed as nonlegumes, among which are the grasses and common grains, many truck and garden crops, and most trees.

Among the latter are two common exceptions, the locusts, and redbud or Judas tree, which are legumes. When legumes are fed to farm animals and the resulting manure returned to the soil, or when the legumes are plowed under directly, succeeding crops get the benefit of the nitrogen fixed by the legumes.

In the soil combined nitrogen occurs mainly in the bodies of living organisms and in the more or less decayed residues from plants or animals which is called *organic matter*. As decay of the organic matter goes on in the soil, the nitrogen is changed to forms which plants use in their growth. In addition, fixation of nitrogen is accomplished in the soil under favorable cropping conditions by organisms other than the legume bacteria.

Mineral soils contain from a few hundredths to 0.25 per cent of nitrogen, or from a few hundred pounds to 5000 pounds of nitrogen in the plowed soil of an acre which weighs approximately 2,000,000 pounds. Very sandy soils contain very little nitrogen but muck soils contain as much as 3 per cent of this element and sometimes more, or 30,000 pounds in the plowed soil which weighs approximately 1,000,000 pounds to the acre. Nitrogen in soils is not very active. A soil containing 5000 pounds of this element under favorable conditions supplies sufficient nitrogen for good yields of grains and grasses. Many vegetable crops, however, respond to additions of nitrogen even to soils that contain 5000 pounds of it to the acre in the surface

six inches. On sandy and other soils low in nitrogen or where it is particularly inactive, most crops will make better growth if nitrogen is added.

Phosphorus—Phosphorus is so active as an element that it occurs in nature only in compounds. A very common compound of phosphorus is calcium phosphate which, together with aluminum and iron phosphates, is present in soils to a greater or lesser extent. Calcium phosphate makes up in large part the bones of animals and it occurs also in the phosphate beds of Florida, Carolina, Tennessee, and the Northwestern states.

Soils contain from less than 0.02 per cent to 0.12 per cent of phosphorus[3] or from 400 to 2400 pounds of this element to the acre in the plowed soil. At first glance this might appear to be an abundance of this element, but soil phosphorus is not readily available to crops. Since soils always have been and must continue to be man's source of food, it is fortunate that phosphorus has not been lost rapidly from the soil. Owing to the slow availability of soil phosphorus, many soils do not furnish crops with enough of this important element for strong normal growth and for the production of satisfactory yields. High lime-requirement legumes such as sweet and red clover and alfalfa make good use of soil phosphorus. On the other hand, crops that are unable to use insoluble phosphorus require the addition of this ele-

[3] Expressed as phosphoric acid these percentages are from 0.05 to 0.27, and from 916 to 5496 pounds to the acre.

ment in soluble forms in order to make satisfactory growth.

Potassium—Potassium, also, being exceedingly active as an element occurs in nature only in compounds. In general, soils are well supplied with this element, containing from 0.42 to 1.67 per cent of potassium [4], or from 8000 to 33,000 pounds in the plowed soil of an acre. Like phosphorus this element occurs in the soil in insoluble minerals. Plants with large root systems in proportion to their potassium needs often obtain from the soil sufficient potash for normal growth. On the other hand, plants with restricted root systems or for any reason unable to use insoluble potassium often fail to thrive unless commercial potassium is added to the soil. The problem is to manage the soil so as to make potassium available for grain and forage crops and to add it for vegetables. Sandy and peaty soils are deficient in potassium; hence it must be added in manure or fertilizers in order that these soils may produce good yields.

Calcium—Calcium occurs in soils in many different minerals, varying greatly in the proportion present in different soils from practically none in some to enormous quantities in others, particularly those recently formed from limestone. Calcium, although a necessary plant-nutrient element, serves also to maintain the proper reaction or balance between acidity and alkalinity in the soil.

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[4] The corresponding figures for potash (K_2O) are from 0.5 to 2.0 per cent and from 10,000 to 40,000 pounds to the acre.

Manganese, Copper, Boron, Zinc—During recent years the use of materials carrying one or more of these elements has proved distinctly beneficial to crops on highly calcareous or on very sandy soils and on some unmanured normal soils. Regular manuring appears to enable many plants to obtain the manganese, copper, boron, and zinc needed for healthy growth. Small quantities of these elements are now being added to fertilizers for certain crops on special soils, but further information on crop response to additions of manganese, copper, boron, and zinc to normal soils is needed as a basis for their economic use in crop fertilization.

THE FERTILIZER INDUSTRY

Some soils are deficient in one element, some in another, and still other soils may be deficient in all of them. Deficiency in the soil of one fertilizer element in available form prevents normal plant nutrition and reduces yields.

Suppose a soil has sufficient available nutrients for a 40-bushel crop of wheat or a corresponding crop of lettuce, except that phosphorus is low. The supply of this element is sufficient for but 20 bushels of wheat, or half a crop of lettuce. As a result of this deficiency, half a crop and no more can be produced on this particular soil until the limiting element has been supplemented in some way. If then we increase the quantity of phosphorus to the same

plane as the other elements, the wheat or lettuce should produce a full crop if all other factors are favorable. Making additions of the limiting element constitutes the use of *fertilizer.* The knowledge on the part of farmers that adding one or two or even three elements increases crop yields has led to the development of the present large and important fertilizer industry.

Fertilizer Tonnage—The tonnage used in the United States from 1880 to 1942 is given in Table I.[5]

TABLE I—TONNAGE OF FERTILIZERS USED IN THE UNITED STATES, 1880 TO 1942.[5] SHORT TONS BY CALENDAR YEARS.

Years	*Thousands of tons*	*Years*	*Thousands of tons*	*Years*	*Thousands of tons*
1880	1,150	1913	6,337	1928	7,985
1890	1,950	1914	7,100	1929	7,974
1900	2,200	1915	5,323	1930	8,163
1901	2,500	1916	5,125	1931	6,306
1902	2,770	1917	5,925	1932	4,336
1903	3,075	1918	6,466	1933	4,871
1904	3,360	1919	6,625	1934	5,547
1905	3,850	1920	7,177	1935	6,221
1906	4,450	1921	4,863	1936	6,820
1907	4,452	1922	5,670	1937	8,226
1908	4,525	1923	6,442	1938	7,548
1909	4,912	1924	6,825	1939	7,766
1910	5,452	1925	7,333	1940	8,302
1911	6,023	1926	7,328	1941	9,240
1912	5,767	1927	6,843	1942	10,005

[5] Willett, Herbert. Fertilizer Consumption in the United States. National Fertilizer Association, Washington, D. C., 1937 and 1943.

The marked increase in the tonnage of fertilizer used in the United States resulted from the relatively low price of fertilizers and the good prices of, and the strong demand for food. Agricultural conservation payments have had an influence but the need for food created by the war is the immediate cause of the great increase in the use of fertilizers. The increase in tonnage from 1938 to 1942 was one-fourth and a further increase occurred in 1943. In that year about 11,000,000 tons were used or double the 1934 tonnage.

Not only has the tonnage of fertilizer used increased over the years but the quantity of plant nutrients in a ton has been increased markedly since 1920. In that year, according to Willett, fertilizers contained as a weighted average, 13.9 per cent or 278 pounds of plant nutrients in a ton. In contrast the percentage of plant nutrients in 1935 and 1936 was 18.2 per cent or 364 pounds of plant nutrients to the ton. This is an increase of nearly one-third in the quantity of plant nutrients in a ton of fertilizer from 1920 to 1935. Based on the quantity of fertilizer used in 1920, Table I, and in 1937, nearly one-half more of actual plant nutrients was used in 1937 than in 1920. In studying fertilizer usage, therefore, the relative concentration of it must be given due consideration.

Owing to the change to stating nitrogen as a per-

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[6] Smalley, H. R. National Fertilizer Association, Washington, D. C. in a personal letter to the author.

centage of nitrogen instead of ammonia as formerly, a further increase in actual nutrients has occurred. One-fifth more nitrogen is now being used in fertilizers than formerly when nitrogen was regularly expressed as per cent of ammonia.

The general trend of fertilizer prices has been downward even though prices have been influenced materially by the usual fluctuations in the general price level. Because of the markedly higher plant-nutrient content, the price reduction per ton of fertilizer is all the more striking. The notable improvent in the efficiency of the manufacture of fertilizers has aided greatly in the lowering of fertilizer prices. Great, indeed, have been the advances made during recent years in both the chemical and the mechanical technique of making fertilizers.

II

NITROGENEOUS FERTILIZER MATERIALS

Nitrogen in fertilizers formerly was expressed as a percentage of ammonia but now the percentage generally is based on nitrogen. Ammonia is represented by the chemical formula, NH_3, which means that one chemical unit, or atom, of nitrogen is chemically combined with three units of hydrogen. The resulting compound, ammonia, is a gas, and although nitrogen itself is a gas it does not occur in fertilizers in gaseous form. Nearly four-fifths of ammonia is actual nitrogen. A fertilizer, therefore, which contains 5 per cent of ammonia has a little more than 4 per cent of actual nitrogen; one with 5 per cent of nitrogen has almost 6.1 per cent of ammonia.

Fertilizers generally contain the same percentage of nitrogen now as they did of ammonia formerly. Consequently, farmers are using one-fifth more nitrogen for crops now than they did before the fertilizer industry changed the method of expressing nitrogen in fertilizer analyses.

A wide range of nitrogen-carrying materials is used in the manufacture of present-day mixed fertilizers. Separate materials carrying nitrogen are often

referred to as "*ammoniates*." A number of ammoniates are of animal or vegetable origin and are called *organic* ammoniates; others are derived from mineral sources, and are termed *inorganic* ammoniates. Another group of comparatively new materials resulting from the commercial fixation of nitrogen from the air are referred to as *synthetic* or *manufactured* ammoniates.

ORGANIC AMMONIATES

Of the organic ammoniates there are two distinct groups, one from animal sources, called *animal* ammoniates, and the other of direct vegetable or plant origin, the *vegetable* ammoniates. In addition to these there are several carriers of nitrogen that contain both animal and plant materials. All of these organic materials when dry have the power of taking up considerable quantities of moisture from other materials in fertilizer mixtures and still retain good drilling qualities. Thus they tend to prevent hardening or lumping, and from that standpoint are referred to as *driers* or *conditioners*. Organic nitrogen has long been more expensive than inorganic nitrogen, but in spite of its greater cost a small quantity of an organic ammoniate generally is, or at least formerly was, used in mixed fertilizers to keep them in proper drilling condition until seeding time arrives which usually is several weeks after the fertilizer is mixed.

Animal Ammoniates—Animal ammoniates in-

clude by-products of the packing and rendering industries such as dried blood, meat meal, tankage, nitrogenous, and garbage tankage, and bone meal, together with waste materials such as hoof and horn meal, hair, and leather scrap from various industries, and fish scrap from canneries, and the pulp from the menhaden fish-oil industry. Although the nitrogen in organic materials is not water soluble, it becomes available to crops rather easily under good growing conditions.

Dried Blood—Dried blood contains from 8 to 14 per cent of nitrogen, depending on the proportion of impurities included. Good blood for fertilizer use has about 12 per cent of nitrogen. In moderately warm weather soil bacteria render the nitrogen in blood readily available to the crop. In the larger slaughtering and packing houses the blood of the animals killed is carefully conserved and dried. The best grades are used in making some kinds of buttons, while the blood of good quality is used in feeds. Only the poorer grades remain for fertilizer use, since the competing button and feed industries can pay a higher price for blood than can the farmer for use in growing crops.

Meat Meal—Meat meal carries from 10 to 11.5 per cent of nitrogen and, varying with its bone content, from 1 to 5 per cent of phosphoric acid. It is similar in every way to and in fact is a high-grade tankage. Most of this product is now marketed as meat scrap for chicken feed, but the poorer grades may go in with high-grade tankage.

Tankage—Tankage has from 5 to 10 per cent of nitrogen, varying considerably with its source, and from 3 to 13 per cent of phosphoric acid. The composition varies with the quality and with the proportion of bone present. Under favorable soil and temperature conditions its nitrogen readily becomes available to crops. Tankage consists of the refuse meat that accumulates in packing plants and meat markets together with the meat of dead animals from rendering plants. The material is cooked under steam pressure which liberates the fats, most of which are skimmed off. The meat is next subjected to pressure to remove as much as possible of the remaining fat, which is undesirable in tankage for fertilizer use. A large share of the better-quality tankage is now used for feeding purposes.

Bone Tankage—Bone tankage is a term applied to tankage containing a high proportion of bone, but which has too much meat to be classed as bone meal. Its nitrogen content varies widely.

Nitrogenous Tankage—Nitrogenous, or process, tankage of good grade carries from 6 to 10 per cent of nitrogen. It is made from waste materials such as wool, silk, hair, feathers, fur scrap, leather, and felt, that are treated with dilute sulfuric acid under steam pressure. The product when dried and ground is a good nitrogenous fertilizer material used mainly in mixed fertilizers. Various trade names are applied to this tankage, depending on where it is made.

Garbage Tankage—Garbage tankage contains

from 2.5 to 3.3 per cent of total nitrogen together with small, but highly variable, percentages of phosphoric acid and potash. It is made from city garbage, and so contains both animal and vegetable refuse materials. After the garbage is cooked under pressure the water is pressed out and the grease removed before it is ground for fertilizer use. This is a low-grade material whose chief value is that of conditioner. It cannot be used in large quantities in high-analysis fertilizers because of its bulk and its low content of plant nutrients.

Fish Tankage—According to official definition "fish tankage, fish scrap, dried ground fish, and fish meal (fertilizer grade) is the dried ground product of rendered or unrendered fish." This product contains from 6.5 to 10 per cent of nitrogen and from 4 to 8 per cent of phosphoric acid.

"Acid fish" is similar to fish tankage except that it has been treated with sulfuric acid to prevent its decomposition. Acid fish contains from 4 to 6.5 per cent of nitrogen and from 3 to 6 per cent of phosphoric acid.

These fish products consist of the offal from fish canneries and of the entire body of non-edible fish such as menhaden and dogfish. Cannery waste is low in nitrogen and high in phosphoric acid as compared with whole fish. The composition of fish tankage and of acid fish, therefore, varies with the proportions of cannery waste and of whole fish used. In the menhaden oil industry the raw fish is steamed under pressure, the oil removed, the pulp dried, and

when ground is ready for market. Whale meat may be treated and used in the same manner.

Bone Meal—Bone meal consists of bones with small quantities of adhering meaty material. Bones accumulate as a by-product in packing and rendering plants. *Raw bone meal* consists of finely ground, dried, but otherwise untreated bones. It carries from 2 to 4 per cent of nitrogen and from 20 to 25 per cent of phosphoric acid. *Steamed bone meal* is made by boiling raw bones under steam pressure after which they are finely ground. During boiling much of the fat and some of the nitrogenous material is removed. Steamed bone meal contains from 1 to 2 per cent of nitrogen and from 23 to 30 per cent of phosphoric acid.

Hoof and Horn Meal—Hoof and horn meal which is another packing-house by-product contains from 11 to 15 per cent of nitrogen. The hoofs and horns are processed for the recovery of glue. Finely ground hoof and horn meal is a high-grade carrier of nitrogen.

Hair—Hair which is a tannery waste product contains from 8 to 10.5 per cent of nitrogen. It has widely varying proportions of foreign materials.

Wool Waste—Wool waste, which consists of short wool and "dirt" removed from the raw wool during cleaning, carries from 3 to 8 per cent of nitrogen.

Leather Meal—Leather meal is made from the scraps and other remains from the manufacture of shoes, harness, and other leather goods. The leather meal which results from the processing and grind-

ing of the scrap has from 6 to 12 per cent of nitrogen.

Leather meal, hair, and wool waste all contain a small percentage of both phosphorus and potash in addition to nitrogen.

Leather meal, hair, wool waste, and similar nitrogenous materials have little fertilizer value in their natural condition. Processing, or treatment with strong acid, however, makes the nitrogen in these materials readily available to crops. This may be accomplished by mixing them with phosphate rock and sulfuric acid for the production of "wet-base" goods. When thus treated these essentially valueless materials not only are disposed of but at the same time are converted into valuable fertilizer.

Sewage Sludge—Milorgonite—Sewage sludge is dried and ground and sold as fertilizer. That from the city of Milwaukee, called *milorgonite,* has from 5 to 6 per cent of nitrogen and from 1 to 5 per cent of phosphoric acid. Milorgonite comes in a granular form. It may be used as a drier.

Guano—Guano consists of the droppings and dead bodies of birds, bats, and seals which have accumulated in rainless regions and in caves. Some of these accumulations are large. The chief sources are the West Indies and islands off the coast of Peru. Peruvian guano is said to have been used as early as 1824 and is therefore the oldest commercial fertilizer used by American farmers; for this reason in some sections farmers still call all commercial fertilizers guano. Guano contains 10.5 per cent of nitrogen and 10 per cent of phosphoric acid.

DRIED PULVERIZED MANURES

Dried pulverized manures may not be commercial fertilizers in the strict sense of that term, yet a considerable tonnage of them is bought and sold annually on the commercial fertilizer market. Dried manures consist of the solid excrement without addition of litter and not including the urine. The solid part is dried and pulverized in preparation for market. These manures are used on lawns, flowers, and gardens and in greenhouses. They contain all three fertilizer elements and organic matter, phosphorus content, however, is somewhat low. The composition of five dried manures is given in Table II.

TABLE II—COMPOSITION OF DRIED MANURES*

Animal	*Nitrogen*	*Phosphoric Acid*	*Potash*
	percent	percent	percent
Sheep	2.50	1.50	1.50
Goat	1.35	1.40	3.60
Poultry	4.50	3.20	1.35
Pig	1.75	1.75	1.00
Cow	1.34	0.90	0.85

Dried manures vary somewhat in moisture content as well as in composition. There is some evidence that nitrogen, phosphoric acid, and potash, one or more of them, have been added as commercial fertilizer materials to increase the plant food content of certain dried manures. These manures might be used as drier in concentrated fertilizers or in super-

* Van Slyke, L. L. Fertilizers and Crop Production. Orange Judd Pub. Co. New York, p. 171, 1932.

phosphate to prevent lumping, but they are too bulky for use in ordinary mixed fertilizers.

Vegetable Ammoniates—All vegetable ammoniates contain small percentages of phosphoric acid and potash in addition to nitrogen. They consist mainly of seeds from which oil, the chief commercial product, has been removed. Plant materials are rated as somewhat slower than are the animal products in yielding their nitrogen to crops. Vegetable ammoniates have special value as conditioner in mixed fertilizers.

Cottonseed Meal—Cottonseed meal has from 6 to 9 per cent of nitrogen, from 2 to 3 per cent of phosphoric acid, and from 1.5 to 2 per cent of potash. The cottonseed is subjected to steam pressure and the oil removed in high-powered hydraulic presses. The remaining cake when ground is common commercial cottonseed meal, the better grades of which are fed to cattle. The poorer grades and surplus meal are used in mixed fertilizers, the meal being an excellent conditioner.

Linseed Meal—Linseed meal has 5 per cent of nitrogen and about 1.5 per cent each of phosphoric acid and potash. It is made from flaxseed, linseed oil being the main product. Most of the linseed meal is fed to dairy cows, but low-grade or off-quality meal may go into fertilizers.

Castor Meal—Castor meal, or pomace, contains from 4.5 to 6.5 per cent of nitrogen and from 1 to 1.5 per cent each of phosphoric acid and potash. It is the ground pulp of castor beans from which the

oil has been removed. Since it is poisonous to livestock, castor meal is used only for fertilizer purposes.

Cocoa Cake—Cocoa cake has from 3.5 to 4.5 per cent of nitrogen. Cocoa shell meal has about 2.5 per cent of nitrogen, 1 per cent of phosphoric acid, and 2.5 per cent of potash. The cake remains after the oil has been pressed out for making cocoa butter. This material is very similar although somewhat inferior to cottonseed meal or castor meal.

Tobacco Stems—Tobacco stems and waste carry from 1.2 to 3.3 per cent of nitrogen, from 4 to 9 per cent of potash, and a much smaller proportion of phosphoric acid. The midribs of the leaves and other waste are ground with the stems and the mixture sold as "tobacco stems." Its main value lies in its goodly percentage of potash and in its effects as a conditioner in mixed fertilizers.

Peat or Muck—Peat or muck when air-dry contains from 1 to 3 per cent nitrogen depending on the material from which it was formed and on the proportion of inorganic matter (silt, clay, and sand) it contains. After drying it is used in fertilizers mainly for its effect as conditioner.

SYNTHETIC OR MANUFACTURED AMMONIATES

Synthetic or manufactured ammoniates are made by combining nitrogen with certain elements by electro-chemical means. The resulting product in turn is combined chemically with other materials to form the compounds used for fertilizer purposes.

Representative fertilizer materials made by these processes are calcium cyanamide, urea, calcium nitrate, sodium nitrate, and sulfate of ammonia. Other fertilizer materials are made by combining, mixing, or adding other compounds to these products.

Cyanamide and urea are regarded as being primarily organic in nature.

Calcium Cyanamide—Pure calcium cyanamide contains 35 per cent of nitrogen. The regular commercial product marketed in the United States carries 22 per cent of nitrogen, while the granular calcium cyanamide has 21 per cent of nitrogen. The dark color of cyanamide, its organic properties, and its value as a conditioner in mixed fertilizers are all imparted to it by its carbon. (Charcoal is composed mainly of carbon.)

Substances toxic to crops develop on exposure of cyanamide to the air. In order to avoid this difficulty the tar-paper-lined bag in which calcium cyanamide is packed should not be opened until immediately before applying the cyanamide to the soil. Furthermore, it appears advisable to use only a moderate quantity to the acre, to put it on ten days before planting time, and to mix the cyanamide with the soil thoroughly soon after it is applied. Cyanamide must not be allowed to touch the seed. For ordinary mixed fertilizer, 50 or 60 pounds of cyanamide to the ton is about the right quantity, although more is sometimes used.

In its manufacture a mixture of quick lime (CaO) and high-grade coke (C) on being heated electri-

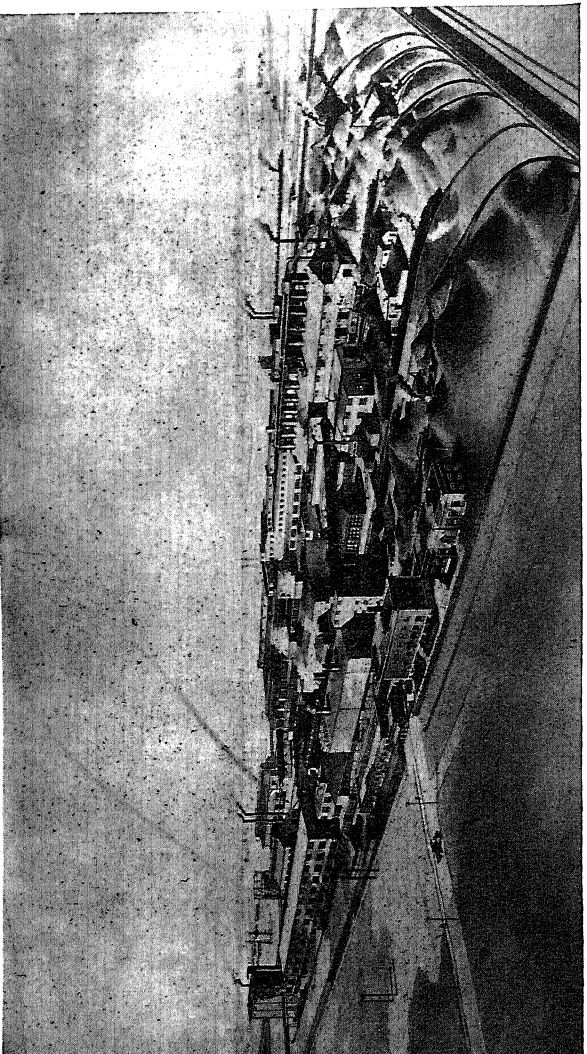


FIGURE 1.—NITROGEN FIXATION PLANT OF THE AMERICAN CYANAMID CO., NIAGARA FALLS, CANADA

This gives an idea of the enormous scale on which synthetic fixation of air nitrogen is carried on. (*Courtesy, American Cyanamid Co.*).

cally to a high temperature form calcium carbide (CaC_2). The carbide is ground and again raised to a high temperature by electrical means. Pure nitrogen (N) on being brought into contact with the white-hot carbide combines with it forming calcium cyanamide ($CaCN_2$). Calcium cyanamide contains calcium equivalent to that in 1300 pounds of good limestone or in about 1000 pounds of good hydrated lime.

Owing to the relatively low cost of nitrogen in cyanamide it may often pay to do the extra work necessary for its proper use, provided the lime in cyanamide is not objectionable. For meadows and pastures the application of calcium cyanamide in the fall after growth ceases or in early spring before growth begins gives best results (Figure 1).

Urea—Urea (CON_2H_4) contains 46 per cent of nitrogen and is the most concentrated fertilizer ammoniate now in use. It is a white crystalline or granular substance. The nitrogen in urea and calcium cyanamide is officially classified as "synthetic non-proteid organic nitrogen."

Urea is manufactured by bringing together pure synthetic ammonia and carbon dioxide under high pressure. Its nitrogen, although in organic form, is water soluble, and becomes available to plants rather quickly in warm soils.

Uramon—Uramon contains 42 per cent of nitrogen which is present in the form of urea. Uramon, the trade name for a modified form of urea, is semigranular and, therefore, relatively free-

flowing in fertilizer distributors. The individual granules are coated with conditioning agents, mainly dark colored, useful, organic materials. These impart to uramon its dark color.

Its usefulness to plants and its action in the soil are essentially the same as of urea. Like urea, uramon is a highly desirable and highly concentrated, readily available nitrogenous fertilizer either for separate application or for use in the higher-concentration mixed fertilizers. When used in mixtures with superphosphate the acidity of the latter should be completely neutralized either by ammoniation or addition of dolomitic limestone or other alkaline materials. For home-mixing the use of ammoniated superphosphate or the addition of alkaline materials to ordinary superphosphate should prove satisfactory.

Nitrate of Soda—As a synthetic commercial fertilizer material in this country nitrate of soda is a newer product than sulfate of ammonia or calcium cyanamide. In the manufacture of this type of nitrate of soda ($NaNO_3$) air, which is almost four-fifths nitrogen (N), and steam are forced through red-hot coke. (The process is shown graphically in the diagram, figure 2). The water is broken down into hydrogen (H) and oxygen (O) in the form of gas. Impurities present are removed and the nitrogen and hydrogen are combined under high pressure into ammonia (NH_3) gas. This is burned (oxidized) with air and forms nitric acid (HNO_3). In a mixer the nitric acid is combined with soda ash (Na_2CO_3)

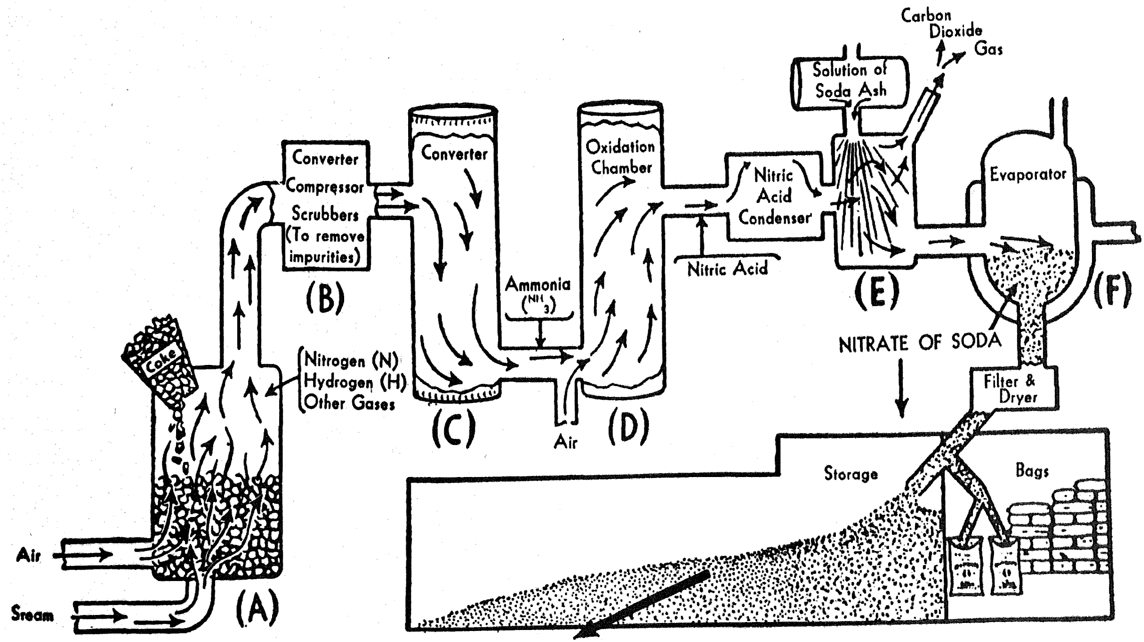


FIGURE 2.—THE FIXATION OF NITROGEN AS NITRATE OF SODA
(Courtesy, the Barrett Company).

to form nitrate of soda ($NaNO_3$) in water solution, which is then evaporated. The resulting solid nitrate of soda is a white material similar in appearance to table salt. Some of the nitrate is made up in the form of white pellets. The pellet form is highly desirable because it takes up water less readily and consequently remains in good drilling condition to better advantage than does the common crystalline form. Synthetic nitrate of soda like its forerunner, the Chilean nitrate, is a highly desirable carrier of nitrogen for many crops. The largest plant in the world manufacturing nitrate of soda is located at Hopewell, Virginia (Figures 2 and 3).

Calurea—Calurea, a mixture of urea and calcium nitrate, carries 34 per cent of nitrogen.

Calcium Nitrate—Calcium nitrate ($Ca(NO_3)_2$) has 15 per cent of nitrogen. Since calcium nitrate takes up moisture readily it is packed in paper-lined bags. It must be protected from moist air. Its nitrogen is in the same available chemical form as that in nitrate of soda.

Cal-Nitro—Cal-nitro is made in two grades, one carrying 20.5 and the other 16 per cent of nitrogen, half of which is in the nitrate and half in the ammonia form.

Calcium nitrate, calurea, and cal-nitro are all granular and contain varying proportions of calcium.

Nitrophoska—Nitrophoska is the trade name for a series of complete fertilizers made in Europe in which synthetic nitrogen is used. Di-ammonium and

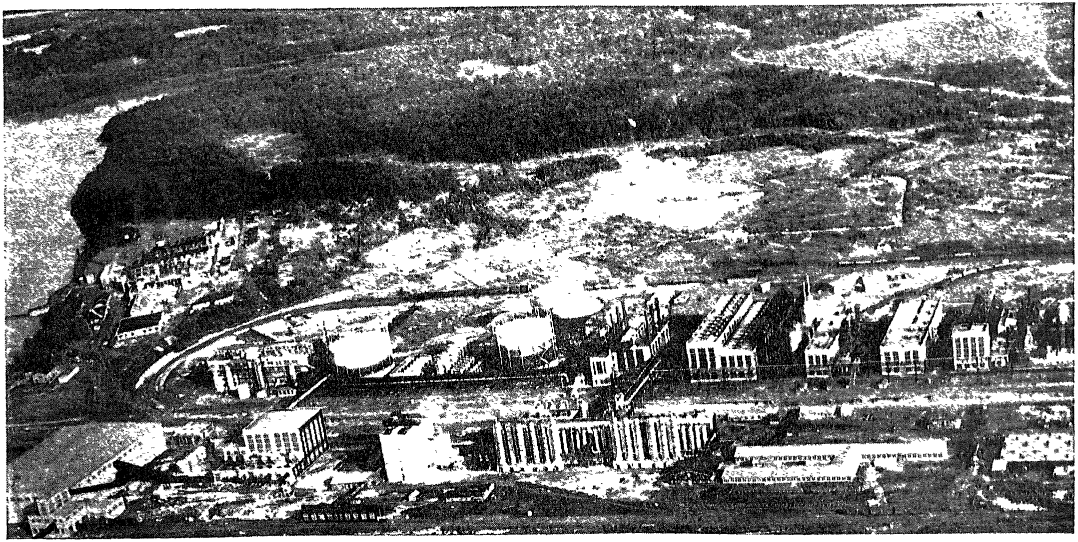


FIGURE 3.—NITROGEN FIXATION PLANT OF THE SOLVAY PROCESS COMPANY AT HOPEWELL, VIRGINIA
This plant is capable of producing an immense annual tonnage of fixed nitrogen.

calcium phosphate, ammonium nitrate, urea, and potash salts are used in making the nitrophoskas. Before World War II four fertilizers were made under this name, 16-16-21 (16 per cent of nitrogen, 16 per cent of phosphoric acid, and 21 per cent of potash), 16-16-16, 10-20-20, and 14-11-26. These fertilizers contain from 48 to 54 units [1] of plant nutrients. Nitrophoska is not coming in during World War II.

Sulfate of Ammonia—During the past few years rapid development has occurred in the process of combining nitrogen (N) and hydrogen (H) into ammonia (NH_3) by means of electricity. The ammonia gas is dissolved in water after which it is combined with sulfuric acid forming sulfate of ammonia ($(NH_4)_2SO_4$). As will be shown presently synthetic ammonia is often combined with other materials. The growth in the production of synthetic ammonia is so rapid as to threaten to displace some of the commonly used ammoniates.

Ammonium Nitrate—Ammonium nitrate (NH_4NO_3) carries 35 per cent of nitrogen. It is white in color and similar in appearance to common salt. It is made by combining ammonia and nitric acid. Except for its deliquescence [2] and explosive properties ammonium nitrate would be an ideal fertilizer material, since there is no residue and because it is rather concentrated.

Ammonium Chloride—Ammonium chloride, or

[1] A unit is 1 per cent in a ton, or 20 pounds.

[2] Any substance that takes up water readily from moist air is said to be deliquescent.

muriate of ammonia, contains 26 per cent of nitrogen. It has good physical properties and may be mixed with muriate of potash and superphosphate without lumping. While desirable for general use such a fertilizer is undesirable for tobacco, potatoes, and other crops that may be injured by chlorine.

Ammonium chloride may be made by combining ammonia direct with hydrochloric acid. A cheaper method, however, is that used in Europe where it is being made by chemical interaction in a mixture of common salt or sodium chloride, ammonia, and carbon dioxide. In addition to ammonium chloride, sodium bicarbonate and other valuable materials are formed as by-products. Made in some such manner as this ammonium chloride may become a very inexpensive ammoniate. Ammonium chloride differs from sulfate of ammonia, or ammonium sulfate, only in that hydrochloric acid is used instead of sulfuric acid. Ammonium chloride, however, has a stronger acidifying effect on the soil than does sulfate of ammonia.

Ammophos—Ammophos is the trade name for ammonium phosphate, a compound of ammonia and phosphoric acid. It is made in two grades, one of which contains 11 per cent of nitrogen and 48 per cent of phosphoric acid. The other grade has 16 per cent of nitrogen and 20 per cent of phosphoric acid. Both grades are valuable concentrated fertilizer materials.

Leunasalpeter—Leunasalpeter is the trade name for the double salt of ammonium nitrate and sulfate

of ammonia. It is a white granular material which carries 26 per cent of nitrogen. It is not explosive as is ammonium nitrate and, being much less deliquescent, is better for fertilizer use. About one-fourth of the nitrogen is present as nitrate; the remainder occurs as ammonia. It is now being made on a large scale in Europe from synthetic materials.

Leunaphos—Leunaphos, which is made in Germany, contains 20 per cent each of nitrogen and phosphoric acid.

Ammoniation—An important recent development in the fertilizer industry is the treatment of superphosphate, or mixed fertilizer containing it, with liquified synthetic ammonia, a water solution of ammonia, or with a mixture of manufactured urea and ammonia in water solution. These are the most economic forms of nitrogen for fertilizer use today. Until recently urea was rather expensive but when thus used this high-grade ammoniate is very economical. Furthermore, the drilling condition of both superphosphate and mixed goods is greatly improved by this ammonia or urea-ammonia treatment. And in addition the time required for the curing of superphosphate or of mixed fertilizer is materially shortened by this means. The direct application of this process, however, is limited to the commercial fertilizer factory.

Farmers who desire to home-mix their fertilizer may profit directly from the application of the ammoniation process by using ammoniated superphosphate and ammophos.

Ammoniated Superphosphate—Ammoniated superphosphate contains 3 per cent of nitrogen and the usual 16 per cent of phosphoric acid. At present some producers add potash to the extent of 2 per cent. The product, therefore, is in fact a complete fertilizer, a 3-16-2.

INORGANIC AMMONIATES

The principal inorganic ammoniates are nitrate of soda and nitrate of potash of mineral origin and sulfate of ammonia, which is a by-product of the manufacture of coke and illuminating gas.

Nitrate of Soda—Nitrate of soda ($NaNO_3$) contains 16 per cent of nitrogen in pellet form and 15.25 per cent in crystal form (both Chilean). Nitrate of soda is the best known and is one of the oldest fertilizer materials on the American market. It is said to have been first imported in 1830. Natural nitrate of soda comes from the west coast of South America, mainly Chile, where it occurs as the chief ingredient of value in an extensive mineral or rock deposit called *caliche.* The caliche is blasted out, loaded into cars and brought to the factory, where the nitrate is dissolved out by water in immense vats. Upon evaporation nitrate of soda crystallizes out, is dried, and bagged ready for use. Nitrate of soda made by the older processes was a coarse dark colored salt, but when made by the new process it is similar in appearance to granulated sugar.

Nitrate salts take up water from the air rather readily and owing to their deliquescence they should always be stored in a dry place in order to avoid lumping. Nitrates being immediately available may be used by the crop as soon as dissolved in the soil moisture, even in cool weather.

Nitrate of Soda-Potash—Nitrate of soda-potash, which is sometimes called nitrapo, contains about 15 per cent each of nitrogen and potash. It is a natural mixture of nitrate of soda and nitrate of potash which occurs in small quantities in the Chilean deposits. Although the proportions vary greatly, there are approximately 3 parts of nitrate of soda with one part nitrate of potash. It is similar in appearance to new process nitrate of soda.

Nitrate of Potash or Potassium Nitrate—Nitrate of potash (KNO_3) carries from 12 to 14 per cent of nitrogen and from 44 to 46 per cent of potash. It occurs in small deposits in various parts of the world, but is not a constituent of the European potash deposits. Nitrate of potash may be made from synthetic nitric acid (HNO_3) and caustic potash (KOH) —a compound of these is made thus: $HNO_3 + KOH = KNO_3 + H_2O$. H_2O, which is water, may be removed by evaporation, leaving potassium nitrate as crystals ready for fertilizer use.

Sulfate of Ammonia—Sulfate of ammonia ($(NH_4)_2SO_4$) contains 20.5 per cent of nitrogen. It is a grayish-colored crystalline material of ideal physical condition for sowing with ordinary fertilizer drills. Unlike the nitrates it does not take up water

readily. Its nitrogen is in the form of ammonia (NH_3). Most of our crop plants are believed to use nitrogen mainly as nitrate (NO_3). That being true, sulfate of ammonia may not act as quickly in cold soils early in the spring as do nitrates. When good growing weather arrives, however, the soil bacteria promptly change the ammonia to the nitrate form, so there is then little difference in the availability of nitrogen, whether supplied in the nitrate or in the ammonia form.

Sulfate of ammonia is made as a by-product of coke ovens and city gas works. In the heating of coal in closed ovens or stills ammonia is driven off with other gases. The ammonia is separated out and conducted into tanks of sulfuric acid where the two unite, forming sulfate of ammonia, which crystallizes out and after drying is ready for fertilizer use.

Table III gives the tonnage of nitrogen in different kinds of ammoniates produced in recent years.

TABLE III—WORLD PRODUCTION OF INORGANIC AND AIR-FIXATION NITROGEN [3]
(Net short tons)

PRODUCT	1909	1913	1917	1924*	1929	1935
Chilean nitrate	330,000	429,000	431,200	372,200	539,000	196,200 [4]
By-product ammonia	233,200	377,300	400,400	346,400	469,700	396,400
Air-fixation nitrogen †	6,050	93,500	374,000	444,500	1,315,600	1,652,900
Total	569,250	899,800	1,205,600	1,163,100	2,324,300	2,245,500

*Year ended May 31. †Greatly increased since 1935. No recent data at hand.

It is interesting to note that Chilean nitrate stood supreme as recently as in 1917. In 1918 by-product

[3] P. E. Howard, Circular 129. Survey of the Fertilizer Industry. U. S. Dept. Agr. 1931.

[4] Data supplied by A. L. Merz, Bureau of Chemistry and Soils, U. S. Dept. Agr.

ammonia held first place, but in 1924 production of synthetic fixed nitrogen exceeded the others. This tonnage supremacy of the synthetic product appears secure. The capacity of fixation plants in the United States, exclusive of Muscle Shoals, was 155,600 tons of nitrogen in 1930 and is much greater in 1944.

For ease of reference the composition of all of the various ammoniates is given in Table IV.

TABLE IV—PLANT-NUTRIENT CONTENT OF NITROGENOUS FERTILIZER MATERIALS

Fertilizer Material	*Nitrogen per cent*	*Phosphoric acid per cent*	*Potash per cent*
	Animal Ammoniates		
Blood (dried)	8–14	...	...
Bone meal, raw	2–4	20–25	...
Bone meal, steamed	1–2	25–30	...
Fish (acid)	4–6.5	3–6	...
Fish tankage	6.5–10	4–8	...
Garbage tankage	2.5–3.3	...	...
Guano	10.5	10	...
Hair	8–10.5	...	...
Hoof and horn meal	11–15	...	...
Leather meal	6–12	...	...
Meat meal	10–11.5	1–5	...
Milorganite	5–6	1–5	...
Nitrogenous tankage	6–10	...	...
Poultry manure (dried)	2.5	0.65	1.5
Sheep manure (dried)	2.33	0.86	1.08
Tankage	5–10	3–13	...
Wool waste	3–8	...	...

Fertilizer Material	*Nitrogen per cent*	*Phosphoric acid per cent*	*Potash per cent*
Vegetable Ammoniates			
Castor meal	4.5–6.5	1–1.5	1–1.5
Cocoa cake	3.5–4.5	...	...
Cocoa shells	2.5	1.0	2.5
Cottonseed meal	6–9	2–3	1.5–2.0
Linseed meal	5.0	1.5	...
Peat	1–3	...	...
Tobacco stems	1.2–3.3	...	4–9
Inorganic and Manufactured Ammoniates			
Ammonium chloride (commercial)	24	...	...
Ammonium nitrate	35	...	...
Ammophos (1)	11	48	...
Ammophos (2)	16	20	...
Ammonium sulfate	20.5	...	...
Ammoniated superphosphate	3	16	2
Calcium nitrate	15	...	...
Cal-nitro	20.5	...	...
Calurea	34	...	...
Cyanamide (commercial)	22	...	...
Leunaphos	20	20	...
Leunasalpeter	26	20	...
Nitrate of soda	16	...	...
Nitrate of potash	12–14	...	44–46
Nitrate of soda-potash..	15	...	15
Nitrophoska*	...	variable	...
Sulfate of ammonia ...	20.5	...	...
Urea	46	...	...
Uramon	42	...	...

* See page 42.

III

PHOSPHATIC FERTILIZER MATERIALS

PHOSPHATIC fertilizers are used to supply crops with available phosphoric acid in which many soils are deficient. Instead of phosphorus (P) the fertilizer industry uses the term phosphoric acid (P_2O_5), which is composed of two atoms of phosphorus combined with five atoms of oxygen. Its true name is not phosphoric acid, but phosphorus pentoxide, which on being dissolved in water does form true phosphoric acid. Actual phosphorus constitutes 43.66 per cent of phosphoric acid. The percentage of phosphoric acid in fertilizers, therefore, is much higher than that of actual phosphorus.

The principal sources of phosphorus are natural deposits of phosphorus-bearing rocks, and iron ores, together with animal bones. Large deposits of high-grade phosphatic rock occur in Florida, Tennessee, South Carolina, Idaho, Utah, Montana, and Wyoming. The largest foreign deposits are found in North Africa. In Montana alone 34,000 acres of phosphate lands have been withdrawn from the area open to settlers. The deposits of phosphate rock east of the Mississippi are small in comparison with those in the Northwestern States. The exact extent of the western deposits is probably not fully known

even yet. A single township in that area is estimated to have 293,000,000 tons of phosphate rock. When it is considered that up to 1913 but 39,000,000 tons had been mined in the entire United States, it is clear that our total deposits of high-grade phosphatic rock will supply our fertilizer needs of phosphorus for many years to come.

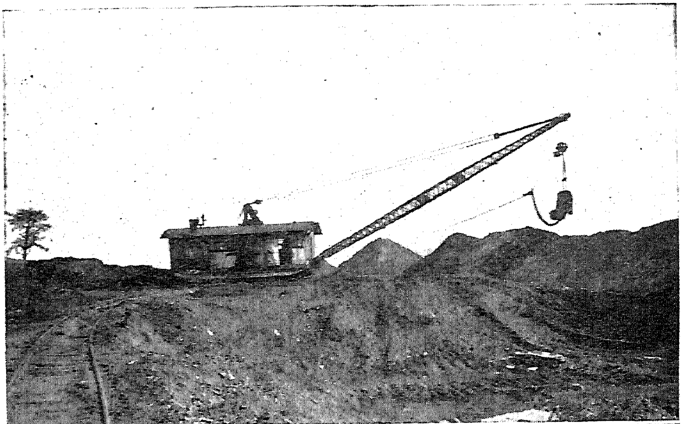
The South Carolina deposit has been known longer than the others. The rock has from 24 to 30 per cent of phosphoric acid (10.6 to 13.2 per cent phosphorus). The Florida rock discovered in 1887 contains from 30 to 35.5 per cent of phosphoric acid (13.1 to 15.5 per cent phosphorus). Much of the Florida rock is made into superphosphate (acid phosphate). The Tennessee phosphate beds were discovered in 1894. The rock carries from 30 to 32 per cent of phosphoric acid (13.1 to 14.0 per cent phosphorus). Canadian apatite, formerly mined in Quebec and Ontario, when rather pure contains 40 per cent of phosphoric acid (17.5 per cent phosphorus).

Phosphatic fertilizer materials may be classified as *natural phosphates,* including rock phosphate and bone meal; *treated, or processed, natural phosphates,* superphosphate, and bone black; *by-product phosphate,* basic slag; and *chemical phosphates,* such as ammophos, leunaphos, and nitrophoska.

Rock Phosphate or "Floats"—Rock phosphate is the finely ground phosphatic rock which is used on the soil in its natural or untreated state. "Floats" is another name for it used in the eastern part of

the United States. It contains from 28 to 32 per cent of phosphoric acid (12.2 to 14.0 per cent phosphorous). Very fine grinding is extremely important, since the material must be very thoroughly mixed with the soil in order to be effective. Manure or green material such as clover in rotting aids in making the phosphorus available to crops. Legumes, especially alfalfa and sweet clover, make good use of phosphorus in this so-called insoluble form. Rock phosphate is not generally recommended for vegetable and truck crops or for field-grown vegetable crops such as potatoes, beans, and cabbage. In the Middle West where two tons of this material can be delivered to the farm for the cost of one ton of 16-per-cent superphosphate, a large tonnage of the rock has been used for corn, oats, wheat, alfalfa, and clover. When it is used under favorable conditions for legumes and grains, rock phosphate yields a good return on the investment. This phosphatic material is but little used in the East, owing to the low organic-matter content of the soil and the long, expensive freight haul from Tennessee or the other phosphate fields (Figures 4 and 5).

Bone Meal—Bone, as stated in Chapter II, is sold either as raw or steamed bone meal. Raw bone meal contains from 20 to 25 per cent of phosphoric acid (8.8 to 10.9 per cent phosphorus), whereas the steamed bone meal has from 23 to 30 per cent of phosphoric acid. The raw bone contains fat which may become coated over the finely ground bone and thus reduce its effectiveness as a fertilizer.



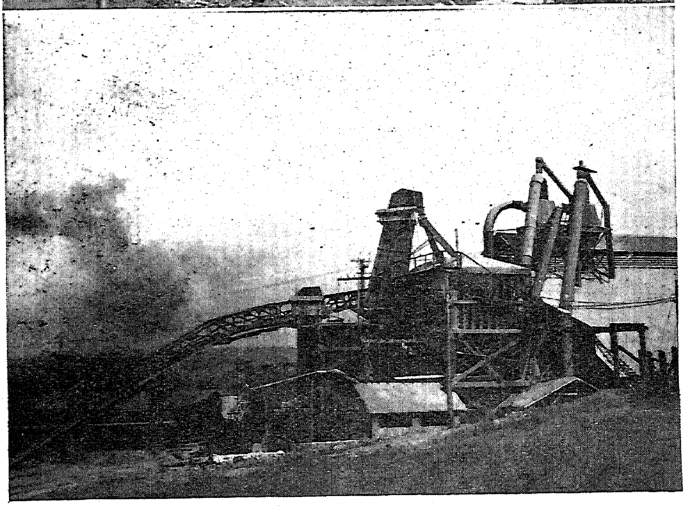


FIGURE 4.—(*Upper*) ROCK PHOSPHATE MINE, TENNESSEE

Drag line outfit stands on rock phosphate from which overburden has been removed.

FIGURE 5.—(*Lower*) ROCK PHOSPHATE GRINDING PLANT, TENNESSEE

(*Courtesy, Ruhm Phosphate and Chemical Co.*).

From the steamed bone meal the fat is removed and the long boiling under steam pressure not only removes the glue, but softens the bone and makes its phosphorus more readily available to the crop. Both raw and steamed bone are very finely ground, in order to make them as effective as possible. Although the phosphorus in steamed bone is not shown as available in analyses, it is used by plants to a marked extent during the season in which it is applied.

Bone Black—Bone black contains from 32 to 35 per cent of phosphoric acid (14.0 to 15.3 per cent phosphorus), from 1 to 2 per cent of nitrogen, and 10 per cent of carbon. It is made by heating bones in a closed vessel, very much as coke is made from coal. Ammonia and other gases are driven off during heating. Bone black is used in refining sugar and oil. After it is no longer of value for refining purposes, it is sold to manufacturers of mixed fertilizers. Its carbon content may give it real value for use in mixed goods as a conditioner in addition to its phosphoric acid and nitrogen.

Superphosphate (Acid Phosphate)—Superphosphate carries from 16 to 45 per cent of phosphoric acid (7.0 to 19.7 per cent phosphorus). Between 6 and 7 million tons of superphosphate are being manufactured annually in the United States. It is the leading material supplying phosphorus for, and in fact is, the basis of mixed fertilizers. From 90 to 95 per cent of the phosphorus used in fertilizers in this country comes from superphosphates. Superphos-

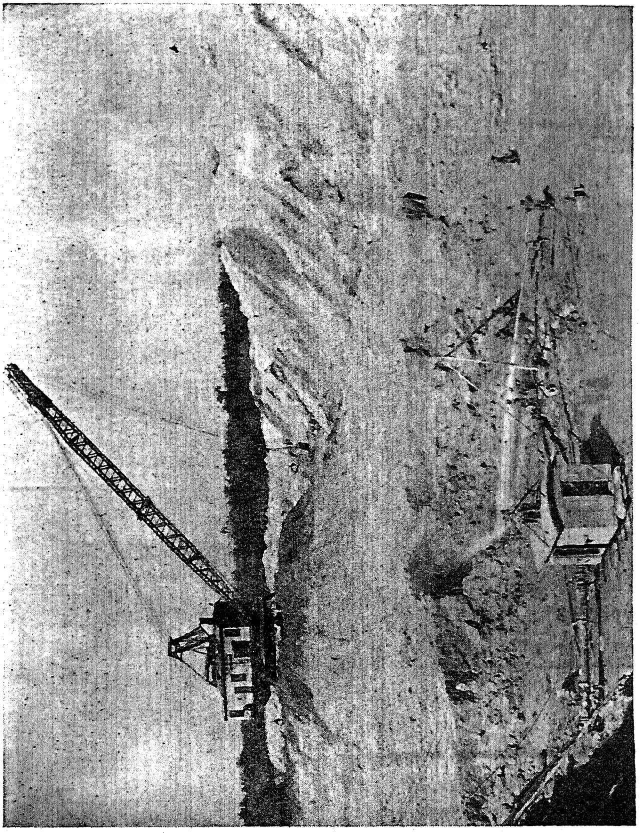


FIGURE 6.—PEBBLE PHOSPHATE MINING IN FLORIDA

The shovel is removing the thick overburden from the phosphate bearing beds. The streams of water loosen the pebble phosphate and accompanying sand and silt.

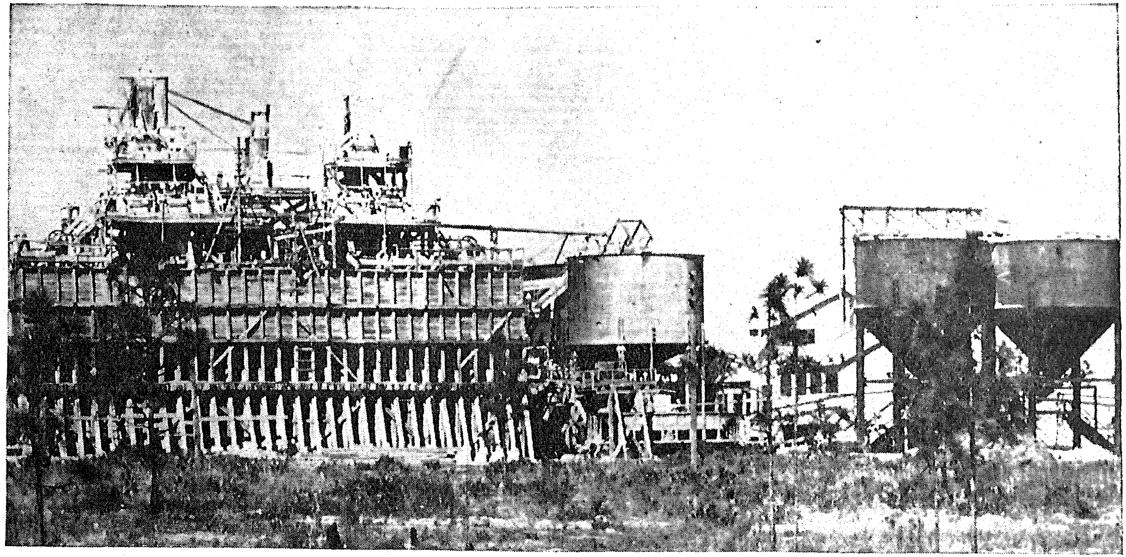


FIGURE 7.—PEBBLE WASHING AND FLOTATION PLANT, FLORIDA

The pebble phosphate and sand and silt are pumped from the mine to the washing plant where the silt is removed from the pebble. The fine phosphate particles are treated and separated by flotation from the sand along with which formerly they were discarded. Thus by recovering a higher proportion of phosphate the life of the beds is being prolonged materially. (*Courtesy, Swift and Company, Chicago*).

phate having from 16 to 20 per cent of phosphoric acid (7.0 to 8.8 per cent phosphorus) is made by mixing approximately 1100 pounds of ground phosphate rock and 900 pounds of sulfuric acid for each ton of finished 16-per-cent superphosphate. These are mixed rapidly in cast-iron pans from which the mixture is poured while still in liquid form into bins where it hardens in a few minutes. After some days the superphosphate may be put through the mill and run back into a pile for further curing. When shipping time comes it is milled again, screened, and bagged or shipped in bulk. This is the ordinary "remilled and screened" superphosphate. A few years ago much of it was bagged and shipped to the farmer without remilling, which resulted in a large quantity of it hardening or "setting up." It was "green" or "immature," the reaction between rock and acid not being complete. At present, however, the manufacturers take great care to insure proper drilling qualities (Figures 6 and 7).

The phosphorus in rock phosphate occurs as tri-calcium phosphate ($Ca_3(PO_4)_2$). When sulfuric acid (H_2SO_4) acts on the rock, hydrogen (H) replaces part of the calcium (Ca), forming mono-calcium phosphate ($CaH_4(PO_4)_2$), and di-calcium phosphate ($Ca_2H_2(PO_4)_2$). Gypsum or calcium sulfate ($CaSO_4$) is formed during the reaction. Practically one half of the weight of 16-per-cent superphosphate thus made is gypsum. For the highest grades of superphosphate, sometimes called *double* or *treble superphosphate,* containing from 40

to 45 per cent of phosphoric acid (17.5 to 19.7 per cent phosphorus), liquid phosphoric acid is used instead of sulfuric acid. This product contains no gypsum, because all the calcium in the rock is combined with phosphoric acid and there is no sulfuric acid used.

Until recently 16 per cent of phosphoric acid (7 per cent phosphorus) was regarded as the standard grade of superphosphate. Eighteen and 20-per-cent goods have been on the market for several years, but now 32-, 40-, and even 45-per-cent grades are being actively offered for sale.

The Tennessee Valley Authority is producing on a small scale phosphatic materials that carry 65 per cent of phosphoric acid.

In fertilizer reports mono-calcium phosphate ($CaH_4(PO_4)_2$), which is soluble in water, is considered "available." Di-calcium phosphate ($Ca_2H_2(Po_4)_2$) is soluble in dilute citric acid, and it too is regarded as "available" to crops. The sum of the percentages of mono- and of di-calcium phosphates, therefore, constitutes the per cent guaranteed to be "available." The term "reverted" was formerly applied to di-calcium phosphate, but it gives the impression of lack of availability, so it seems better to discard it. Tri-calcium phosphate, ($Ca_3(PO_4)_2$), regarded as insoluble, is considered "unavailable."

When placed in storage for a considerable length of time the ordinary grades of superphosphate have had the reputation of lumping or "setting up." Limestone and hydrated lime have been used to re-

duce this difficulty, but apparently without all of the desired benefits. A small quantity of dry peat or muck or low-grade tankage or other organic waste product mixed with the superphosphate when being remilled might aid greatly in reducing lumping.

Ammoniated Superphosphate—Ammoniated superphosphate contains 3 per cent of nitrogen and 16 per cent of phosphoric acid (7 per cent phosphorus) together with 2 per cent of added potash. Ammonia in gaseous or liquid form is brought into contact with superphosphate in a closed vessel. Ammonium phosphates and a very small quantity of sulfate of ammonia are formed in the superphosphate.

Basic Slag—Basic slag contains from 10 to 25 per cent of phosphoric acid and considerable lime. American slags are rather low in phosphorus and consequently are not very generally used for this element.

Basic slag is made from pig iron containing phosphorus, which is objectionable in steel. Blowing air into the molten mass of iron in a container lined with dolomitic limestone causes the phosphorus to unite with the lime and silica. The slag comes to the top of the molten or liquid iron and is poured off, hardening into a glassy brittle mass. The material is finely ground for use on the soil. Not less than 70 per cent of it should pass through a 100-mesh screen (U.S. Bureau of Standards sizes) and 90 per cent or more through a 50-mesh screen. Some manganese is present which may be of value, also iron, which occasionally is not available in soils in

sufficient quality for best crop growth. The phosphorus is soluble in citric acid and is rated as "available" to crops. Phosphorus in slag does not change in the soil to less available forms as it does in superphosphate. This fact together with its large percentage of lime makes basic slag an especially desirable phosphatic material for use on sour soils which are not otherwise limed. Since its lime reduces acidity and the phosphorus remains available in sour soils, basic slag is probably the best single commercial fertilizer material other than an ammoniate for use in grassland pasture fertilization, particularly on acid soils that carry a mixture of legumes and grasses.

Phosphate of Potash—Phosphate of potash may vary from 32 to 53 per cent of phosphoric acid (14 to 23 per cent phosphorous) and from 50 to 30 per cent of potash. As the phosphoric acid increases the potash content decreases. This is a highly concentrated material that may be made by heating caustic potash with calcium phosphate. It is, however, not a compound of potash and phosphoric acid. Although not yet on the fertilizer market in large quantities, it may come into common use in the more concentrated mixed goods.

The composition of the following materials described in Chapter II, is given in Table V.

In the carriers listed in Table V ammonia is combined with phosphoric acid instead of sulfuric acid as in sulfate of ammonia, thus giving a fertilizing material which may have from 30 to 50 units of

plant nutrients as compared with 20.5 units in sulfate of ammonia. These materials are useful in making highly concentrated fertilizers.

The phosphorus in these materials is rated as readily available, as is also that in superphosphate. Basic slag is next in availability, followed by steamed bone meal, whereas raw rock phosphate probably ranks last in availability to most crops.

TABLE V—COMPOSITION OF CHEMICAL PHOSPHATES

	Phosphoric acid per cent	*Phosphorus per cent*
Ammophos	20	8.7
Ammophos	48	20.1
Leunaphos	20	8.7
Nitrophoska	20	8.7

For ease of reference the data on the plant-nutrient content of the phosphorus-carrying fertilizer materials is given in concise form in Table VI.

TABLE VI—PLANT-NUTRIENT CONTENT OF PHOSPHATIC FERTILIZER MATERIALS

	Phosphoric acid		*Nitrogen*	*Potash*
	Not available per cent	*Available per cent*	*per cent*	*per cent*
Basic slag	......	10-25	......	......
Bone black	32-35 *	......	1-2	......
Bone meal (raw)	20-25 *	......	2-4	......
Bone meal (steamed)	23-30 *	......	1-2	......
Phosphate of potash	......	32-53	......	50-30
Rock phosphate	28-32	......	......	......
Superphosphate	......	16-45	......	......
Superphosphate, ammoniated	......	16	3	2
Metaphosphate (T.V.A.)	......	63	......	......

*Total phosphoric acid.

IV

POTASH FERTILIZER MATERIALS

SOILS other than sands, peats, and mucks have large supplies of potash, but it occurs mainly in insoluble minerals. For this reason many crops on fine- and medium-grained soils and most crops on sands, peats, and mucks respond to applications of water-soluble potash. The term potash as used in fertilizers in reality means potassium oxide (K_2O), a compound of potassium and oxygen of which potassium constitutes 88.66 per cent.

Recognition of the possible embarrassment of American agriculture and industry because of their complete dependence on foreign sources of potash led to the inauguration in 1911 of investigations with a view to the establishment of an American potash industry. At almost the very beginning of this work came the World War which, by cutting off the usual supplies, brought on an acute potash shortage in this country. This situation proved the wisdom of undertaking these investigations into possible domestic sources of potash. Furthermore, the shortage forced the immediate development of means for producing potash from the different raw materials and industrial by-products which, according to the investigations, held promise of commercial success.

Among the possible sources of potash studied were the seaweed kelp, growing in abundance on the Pacific Coast, widely-occurring potash-bearing minerals, the potash brines of saline lakes in Nebraska, Oregon, Utah, New Mexico, Nevada, and California, furnace and flue dusts, and wastes from the manufacture of industrial alcohol. Some of these have proved to be of practical value.

DOMESTIC SOURCES OF POTASH

Wood Ashes—Wood ashes as a source of potash are of moderate but diminishing importance in the vicinity of sawmills and wood-working factories in this country. Unleached hardwood ashes carry from 4 to 7 per cent of potash, from 1.5 to 2.0 per cent of phosphoric acid and from 20 to 35 per cent of lime (CaO). Leached ashes, on the other hand, seldom contain more than one per cent of potash.

During the pioneer days the forests were cut and burned and the potash was leached from the resulting ashes. This potash, which was sold in foreign lands, was an important source of income at the time. For many years, however, the United States has imported many times the tonnage of potash that was exported during those days of early development of this country.

Industrial Wastes—The recovery of potash as a by-product of the manufacture of alcohol from molasses was begun as an emergency measure during the World War and has been continued since that

time. This product, which is called "*Vegetable Potash*," carries about 33 per cent of actual potash, (K_2O). Potash is being recovered from cement kiln fumes and flue dusts, also. This is an important source of potash, the recovery of which is capable of wide expansion in the cement industry. In fact, even moderately complete recovery of potash from industrial wastes in this country would go far toward supplying the potash needs of American agriculture.

Tobacco Stems—Tobacco stems (Chapter II) contain from 4 to 9 per cent of potash which is mainly in water-soluble form.

Saline Lake Deposits—As already indicated old, dry lake beds in the more or less arid sections in the western part of this country were studied as possible sources of potash. Work at Searles Lake in California was begun in 1912, and it proved to be the most important of the saline lakes studied. Since that time consistent, intelligent research and the employment of technical skill have developed an important chemical industry. One of its chief products is muriate of potash which contains 99 per cent of potasium chloride (KCl), equivalent to almost 62 per cent of potash. This product is one-fourth richer in actual potash than the 50-per-cent grade which has long been the standard of the fertilizer industry. Other products of the Searles Lake development are borax, boric acid, sodium sulfate, and sodium carbonate (Figure 8).

Americans may well be proud of this outstanding

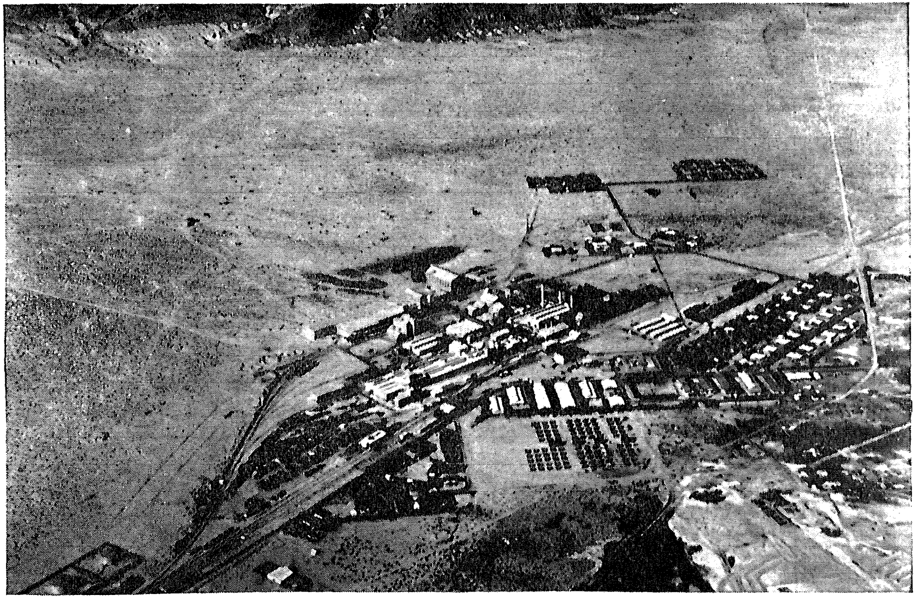


FIGURE 8.—AMERICAN POTASH AND CHEMICAL COMPANY PLANT AT TRONA, SEARLES LAKE, CALIFORNIA

This gives only a partial idea of the extent of the Searles Lake deposit of potash bearing salts. (*Courtesy, American Potash and Chemical Co.*).

chemical achievement, which has been carried out by the American Potash and Chemical Corporation.

Underground Potash Deposits—As a matter of interest the following paragraph from the 1928 edition of the *Handbook of Fertilizers* is repeated here.

"Seventy counties of Texas are more or less completely underlain by beds of potash-bearing salts varying greatly in thickness and purity. Present information indicates that these salts contain from 5 to 23 per cent of actual potash. More complete information is needed, and it would appear to be a proper function of our Federal Government to explore these deposits, since they might prove exceedingly useful during periods when supplies from present sources were cut off or seriously threatened."

The twenty years of search for sources of domestic potash have been well spent and the country has been amply rewarded for the time and money used by the discovery in 1925 of rich potash deposits near Carlsbad, New Mexico, at about 1000 feet below the surface. These deposits consist of millions of tons of high-grade potash-bearing minerals. Following this epoch-making discovery, several years were required to explore the area, to sink shafts, to install the necessary hoisting and grinding machinery, to erect the refining plants, and to get into actual production of potash. This is indicated by the sales of domestic potash over the past ten years. In 1925 the sale of the domestic product in the United States was 25,802 tons of actual potash

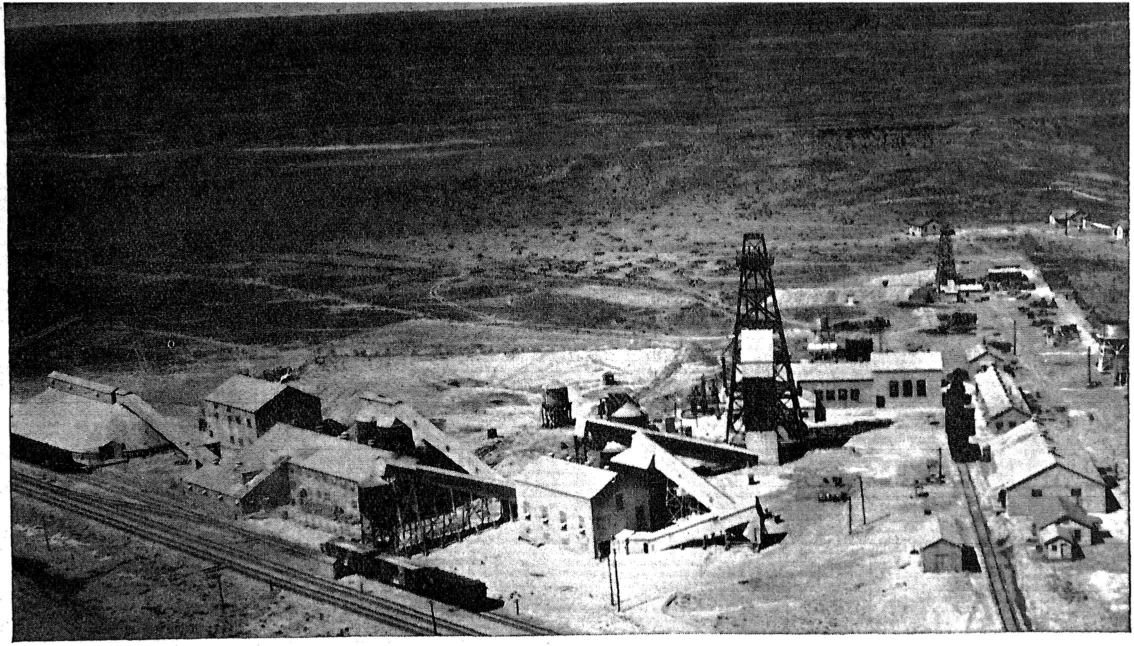


FIGURE 9.—MINE AND REFINERY, POTASH COMPANY OF AMERICA, CARLSBAD, NEW MEXICO
Mine shaft in right foreground and refinery and storage buildings at left. (*Courtesy, Potash Company of America*).

(K_2O). The consumption increased to almost 64,000 tons in 1931, but dropped materially in 1932. In 1933, the first year of production in the New Mexico area, 138,770 tons of domestic potash were consumed in the United States. In 1934, however, even though production increased slightly over the previous year, consumption of domestic potash dropped to 113,250 tons (Figures 9, 10, and 11).

Since 1934 the capacity of the American potash industry has been increased to more than double the actual production of crude potash salts mined that year in the United States. In fact, American agriculture now is independent of foreign potash because domestic productive capacity is well above the present total annual consumption of potash on American farms. At the current relatively low price of potash it appears probable that potash consumption can be increased materially with real economic advantage to American agriculture.

The American standard-of-living wage scale, unfavorable foreign exchange rates, and lack of tariff protection may handicap the American potash industry for a time. At present foreign producers may dump without restriction their excess potash production on the American market. Even so the domestic potash industry produced nearly half of the fertilizer potash used on American farms in 1934.

In 1931 the United States Potash Company completed its first shaft for hoisting potash in its mining operations. The Potash Company of America finished its first shaft in December 1933. The Inter-

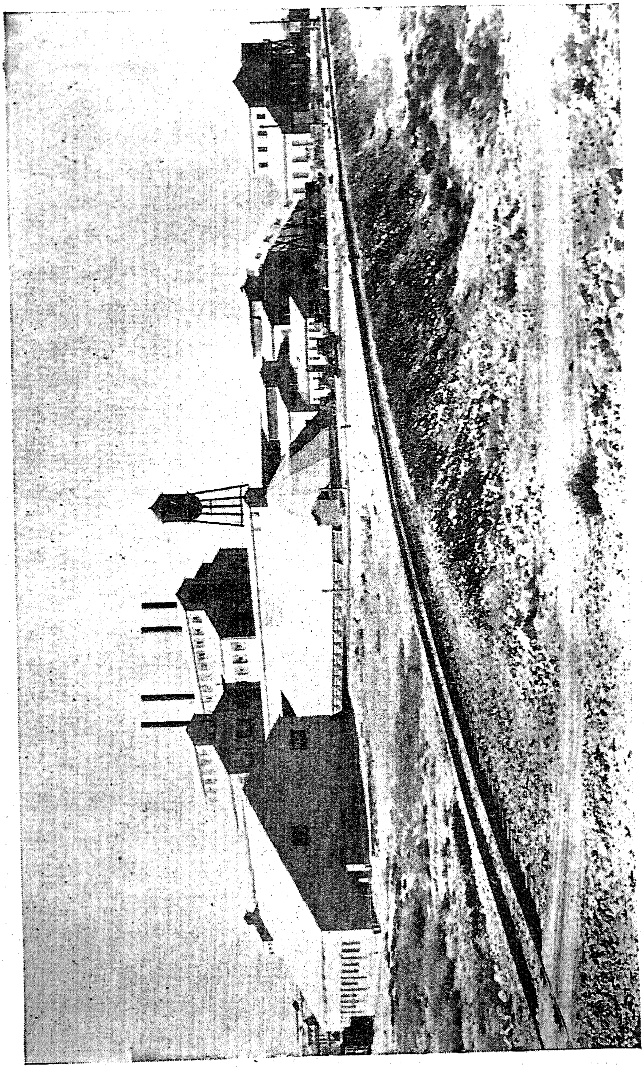


FIGURE 10.—REFINERY BUILDINGS AND WAREHOUSES, UNITED STATES POTASH COMPANY, INC., CARLSBAD, NEW MEXICO

national Minerals and Chemical Corp. was in production in 1940. These three producers located near Carlsbad, New Mexico, employ the latest technical methods from mining crude salts to bagging refined potash. Some of the potash is marketed as manure salts (25% K_2O) but most of it is sold as muriate of potash (KCl, 60-62% K_2O).

In 1936 the farmers of the U. S. used 376,000 tons of potash (K_2O) on the soil, in 1937, 462,000 tons, in 1938, 441,000, in 1939, 347,000, in 1940, 412,000, in 1941, 533,000, 1942, 539,000, and in 1943, 560,000 tons of actual potash (K_2O). These data were supplied by Turrentine. Before 1939 about half of the potash used was imported. Since then, however, domestic producers have supplied the potash used on the soils of this country and in addition have exported potash to Latin America and Canada. Total domestic production was more than 700,000 tons of actual potash in 1943, a notable achievement.

FOREIGN SOURCES OF POTASH

The leading sources of foreign potash for fertilizer use are the immense underground deposits in five districts in Germany, and similar deposits in France, Poland, Russia, and Spain. Chile supplies a small quantity of potassium nitrate, and potash is recovered from the brines of the Dead Sea in Palestine.

In Europe the potash-bearing salts occur at depths of from 1000 to almost 5000 feet below the surface of the earth, but because of the enormous expense

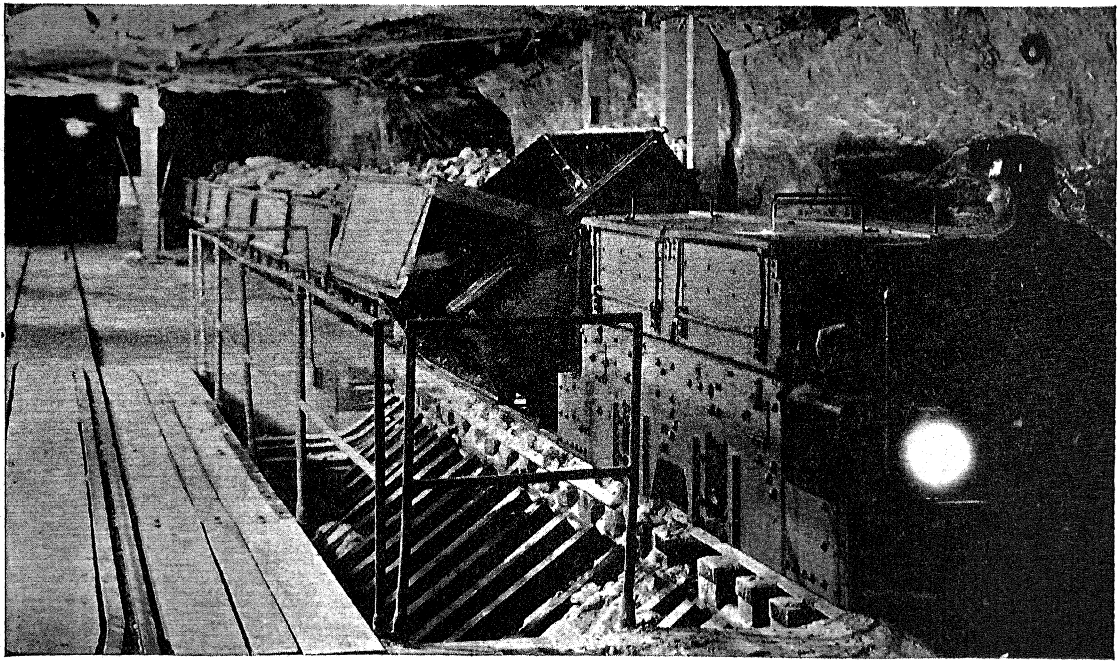


FIGURE 11.—UNDERGROUND ORE TRAIN, UNITED STATES POTASH COMPANY, INC.
(*Courtesy, United States Potash Company, Inc.*).

of mining, little potash is now being taken out from depths greater than 3500 feet below the surface. It occurs as salts mixed with gypsum, rock salt, and other materials in beds varying in thickness up to 3000 feet in parts of the Stassfurt deposit in Germany. The richest salts are ground and used in fertilizers without refining but most of the potash is refined near the mines. The refining process is fairly simple, since each salt crystallizes out of solution at a definite temperature. It is desired to obtain potassium chloride, for example. The crude salt as mined is dissolved in water, and all salts with a crystallization temperature higher than that of the chloride are removed. Then the solution is held at the proper temperature for the potassium chloride to crystallize out of solution, the liquid in the vat is drawn off. The salt is washed, and then dried ready for shipment. Europe supplies potash as muriate, sulfate, mixed salts, carbonate, manure salts, and kainit (Figure 12).

Table VII on page 74 shows the quantity of each salt imported in 1922, in 1934, and in 1936.

In 1922, 186,264 tons of actual potash were imported into this country; in 1923, 209,950; in 1924, 200,365; in 1929, 268,000; in 1934, 124,658, and in 1936, 197,404 tons of potash (none in World War II).

FERTILIZER POTASH SALTS

All of the commonly used carriers of potash are soluble in soil moisture, so all of them possess practically the same ready availability for crops.

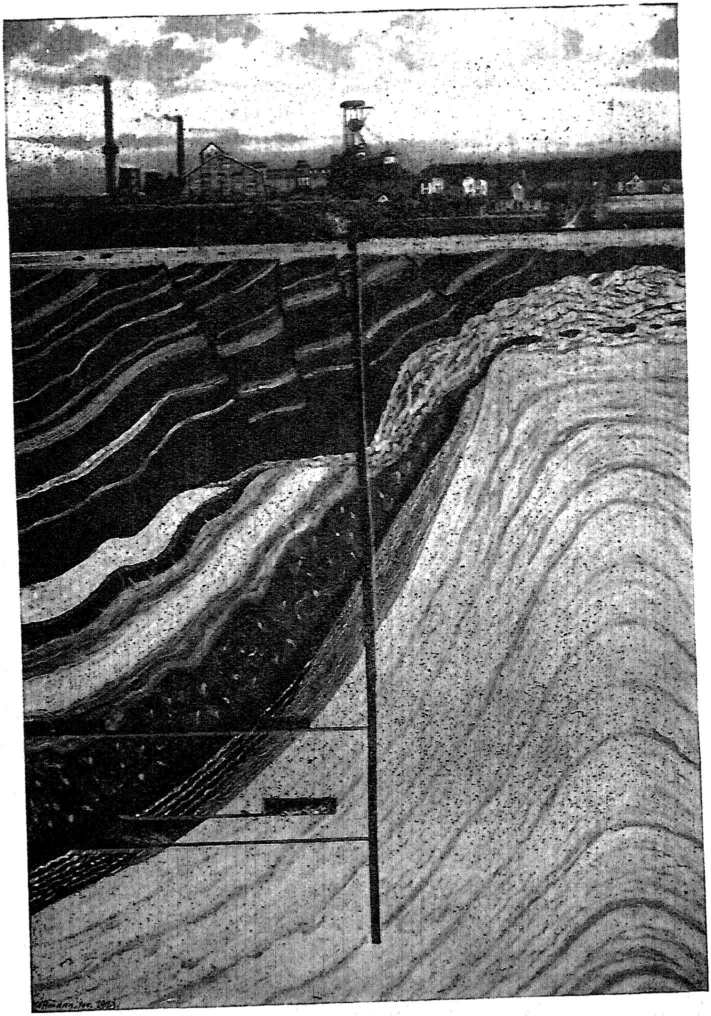


FIGURE 12.—EUROPEAN POTASH DEPOSIT

This shows the refining plant and a cross section of the mining operations. The white bands among the black show the beds of potash salts. (*Courtesy, N. V. Potash Export My. Amsterdam, Holland*).

Muriate of Potash—Muriate of potash or potassium chloride (KCl) contains from 50 to 62.5 per cent of actual potash (potassium oxide K_2O). It occurs in small gray crystals. Not being deliquescent, it is a very satisfactory material either for separate application or for use in mixtures. Its chlorine is considered objectionable in tobacco production, but, because the muriate is rather concentrated and cheaper than other potash salts, it is used more widely than any other carrier of potash in the higher-analysis mixed fertilizers for general use.

TABLE VII—POTASH IMPORTED IN 1922, 1934, AND 1936.
(Expressed as short tons, 2000 pounds)

	1922*		1934†		1936§	
	Tons of Salts	*Tons Actual Potash*	*Tons of Salts*	*Tons Actual Potash*	*Tons of Salts*	*Tons Actual Potash*
Kainit	169,287	20,992	127,566	17,859	59,292	11,761
Manure salts	218,406	43,681	88,797	22,200	39,053	12,263
Muriate of Potash .	179,484	89,742	100,511	50,255	235,959	133,081
Sulfate of Potash ..	65,534	31,849	35,671	16,612	59,581	29,791
Nitrate of Potash and other salts	......	......	56,761	17,732	61,513	10,508
Total	632,711	186,264	409,306	124,658	455,398	197,404

*Turrentine, J. W., Potash, pp. 4-6, Wiley & Sons, New York, 1926.
†Turrentine, J. W., The Mineral Industry, pp. 474-489, McGraw-Hill Book Company, Inc., New York, 1935.
§Hedges, J. H., Minerals year book, Review of 1936, U.S. Dept. Interior, Bureau of Mines, 1937.

Sulfate of Potash—Sulfate of potash, or potassium sulfate (K_2SO_4), has 48 per cent of potash and not more than 2.5 per cent of chlorine. This salt is light gray in color and remains dry in shipment or

in good storage. The sulfate is regarded as much better for tobacco and possibly somewhat better for potatoes than the muriate. So long as the sulfate costs about ten dollars a ton more than does the muriate, the latter will be the more widely used. Sulfate of potash is obtained from crude salts, but it is made mainly by treating muriate of potash with magnesium sulfate.

Sulfate of Potash-Magnesia—Sulfate of potash-magnesia is expected to carry not less than 25 per cent of actual potash (it may go as high as 30 per cent), 25 per cent of sulfate of magnesia, and not over 2.5 per cent of chlorine. It is a double sulfate of potash and magnesia made from the muriate or from kainit. For tobacco culture this material is regarded as superior to other potash salts.

Carbonate of Potash—Carbonate of potash contains from 15 to 50 per cent of actual potash, depending on the material from which it is produced. It is white in color and takes up water very readily. It may be obtained from the ashes of wood, beet-sugar residue, cottonseed hulls, and similar materials. In 1924 more than 8,000 tons of actual potash, chiefly for the chemical industries, was imported into this country in the carbonate form. The carbonate may cost somewhat more than the other forms, but for tobacco and for use on some peat or muck soils, in particular, a demand for carbonate of potash may develop.

Carbonate of Potash-Magnesia—Carbonate of potash-magnesia is a manufactured carrier of potash.

It comes in a dry, finely-powdered condition and carries from 24 to 27 per cent of potash (K_2O). This material contains about 35 to 40 per cent of potassium carbonate and approximately the same proportion of magnesium carbonate.

Nitrate of Potash—As already stated in Chapter II nitrate of potash carries from 44 to 46 per cent of potash in addition to 13 per cent of nitrogen. Nitrate of potash occurs in natural deposits and is made from nitrate and potash salts. It has the advantage of being rather concentrated and so can be used in the more highly concentrated fertilizers now in use.

Manure Salts—Manure salts carry from 20 to 30 per cent of potash. Formerly the crude salt as mined, carrying about 20 per cent of potash, was marketed as manure salts. This carrier consists mainly of muriate and a little sulfate of potash, along with common salt and numerous impurities. Some of the potash mined at Carlsbad, New Mexico, is ground and sold direct as manure salts. These natural salts carry as much as 26 per cent of actual potash, but a potash content of 30 to 50 per cent may be obtained by mixing refined salts with the natural ones. Manure salts from abroad containing more than 20 per cent of potash are usually more or less refined.

Kainit—Kainit, carrying from 14 to 20 per cent of potash mainly as the muriate, is the crude salt as mined and is ground to a proper fineness in preparation for market. In color it varies from gray or

white to pink, depending on the different salts composing it. It contains much chlorine.

Such materials as the nitrophoskas (page 40) and other chemically-made complete fertilizers, phosphate of potash (page 60) and the organic ammoniates, more especially the vegetable ones, carry varying quantities of potash.

For ready reference the data on plant-nutrient content of the potash fertilizer materials is brought together in Table VIII.

TABLE VIII—PLANT-NUTRIENT CONTENT OF POTASH FERTILIZER MATERIALS

Carrier	*Potash (per cent)*	*Nitrogen (per cent)*
Ashes (wood)	4–7	......
Carbonate of potash	15–50 *	......
Kainit	14–20	......
Manure salts	20–30	......
Muriate of potash	50–62.5	......
Nitrate of potash	44–46	13
Sulfate of potash	48–52	......
Sulfate of potash-magnesia	25–27	......
Carbonate of potash-magnesia	24–27	......
Tobacco stems	4–9	1.2—3.3

*When of exceptional purity the potash content of carbonate of potash may be as high as 65 per cent.

Special Acknowledgment—Information concerning the latest developments in the production of American potash has been supplied to the writer by Mr. J. W. Turrentine, president of the American Potash Institute, and by the American potash producers. For this assistance the writer makes grateful acknowledgment.

V

EFFECTS OF FERTILIZERS ON CROPS AND SOILS

INFLUENCE OF FERTILIZER ELEMENTS ON CROPS

EACH element has its own particular function in, and effects on, plant growth. Much is yet to be learned, but we know something of the function, influence, and effects on plant growth of nitrogen, phosphorus, and potassium, the so-called "fertilizer" elements as used in commercial fertilizers.

Nitrogen—Nitrogen has a quick, outstanding effect on plant growth, whenever it is used in moderately large quantities. Its first effect is to stimulate the growth of leaf and stem, the vegetative part of the plant, somewhat as does abundant rainfall. It gives to leaves a decidedly dark green color, whereas lack of sufficient nitrogen is often indicated by a yellowish color of the leaves and short growth of the stalk or stem. In grains abundance of nitrogen causes the growth of tall weak stalks. Nitrogen in the plant seems to control the utilization of phosphorus and potassium. It tends to produce watery, succulent growth, very desirable in such crops as lettuce, spinach, and celery, but undesirable with such crops as tomatoes, strawberries, and the grains.

Farmers often misinterpret the results from a lit-

tle nitrogen in a mixed fertilizer on grain as compared with the effects of superphosphate, or of no fertilization. This misconception results from the stimulation of stem and leaf growth by a small quantity of available nitrogen somewhat earlier in the season than the period during which the crop may obtain ample nitrogen from the soil through the active decay of organic matter by soil organisms. This early apparent advantage from the use of a little nitrogen often disappears completely before harvest time arrives.

Nitrogen applied in too large quantities causes trouble more often than do the other elements. Excessive use of nitrogen may have several important detrimental effects.

It may delay ripening by causing too much vegetative growth of crops like tomatoes. Too much nitrogen causes peaches to be late in ripening and to be of poor shipping quality, and the wood of fruit trees may not mature until so late that winter injury often results.

Lodging of grain may result from weakening of the straw through excessive lengthening of the internodes. After lodging has occurred, the heads seldom fill properly and the grain is likely to be chaffy.

Too much nitrogen may lessen resistance to disease by bringing about unnatural conditions of nutrition within the plant and by causing the cell walls to be so thin, succulent, and easily penetrated that infection by disease organisms is easily accomplished.

Phosphorus—Phosphorus is absolutely essential in many phases of plant growth. Fat and albumen do not form without it, and although starch forms, it cannot change to sugar without phosphorus. Seeds are usually richer in phosphorus than are other parts of the plant. It appears, therefore, to have an important function in seed development. Phosphorus hastens ripening, which is very important with such crops as corn and tomatoes in sections having a short growing season. Adding phosphorus sometimes hastens maturity sufficiently to enable a crop to escape serious frost damage. Moreover, some evidence has accumulated to the effect that frost is less detrimental to crops which have received ample phosphorus.

Phosphorus encourages the growth of roots, but more especially the development of the root hairs. Crops with restricted root systems are benefitted most in this way. In order that plants may obtain sufficient nutrients for healthy growth, the roots must permeate the soil in all directions. A fall-sown crop such as wheat shows the marked benefits of phosphorus in its increased fall and early spring growth. Through its effect on root development and by increasing vigor, phosphorus aids a crop like wheat in withstanding the rigors of winter and the sudden temperature changes of early spring.

As already stated seeds are richer in phosphorus than are other parts of the plant; consequently a good supply of available phosphorus increases the yield of grain as compared with straw. By bal-

ancing the weakening effects of nitrogen phosphorus strengthens the straw and thus reduces the tendency of small grains, especially oats, to lodge. Phosphorus plumps the kernel of grains and improves the tone and vigor of the plant and the quality of the crop. Improvement in quality is especially notable when mature grain or ripe fruit such as of peaches, tomatoes, or peppers is concerned.

No undesirable effects have been noted from the use of phosphorus even in ordinarily heavy applications. It is conceivable, however, that with a small supply of nitrogen available, extremely large applications of phosphorus, particularly on droughty soils, might hasten ripening of a crop so greatly as to reduce the yield, but this difficulty need not be expected with average or even moderately heavy applications.

Crops show shortage of nitrogen by a light green or yellowish color, but with many plants there is little, if any, evidence of a shortage of phosphorus until harvest time, when it is shown by a low yield of grain, fruit, or seed. Phosphorus increases resistance to disease by balancing the weakening effects of nitrogen and making possible a more balanced normal growth.

Potassium—Available potassium in proper quantity has much to do with vigorous growth. Like phosphorus it increases the plant's natural resistance to disease through balancing the effects of nitrogen. Potassium, however, in common with nitrogen tends to delay ripening, thus counteracting the ef-

fects of phosphorus. In general it has a balancing effect on both nitrogen and phosphorus.

Potassium is needed for the formation of the green part of plants called *chlorophyl,* which with the aid of sunlight brings about starch formation, for which potassium is absolutely necessary. Through its aid in starch formation potash, like phosphorus, helps plump the grain of cereals. Potassium in extremely heavy applications on mineral soils may sometimes be harmful to crops, and there is little doubt but that potassium in heavy applications, direct for lettuce, or accumulations of it in the soil from the fertilizer used on preceding crops, frequently causes heavy damage to this crop on some peat soils.

EFFECT OF FERTILIZER RESIDUES ON SOILS AND CROPS

Many fertilizer materials consist of two radicals, or chemical parts—one an acid, the other a metal or a basic substance such as ammonia (NH_3), which functions like a metal. Bases unite with acids and thus counteract their effects and in so doing form salts. In a salt such as muriate of potash, for example, potassium the plant-nutrient part is a metal, whereas the chlorine forms an acid and removes lime and other basic materials from the soil. In nitrate of soda, on the other hand, the nitrate, which is the fertilizer part, forms an acid; the soda is a metal or base. Crops use the nitrate portion of nitrate of soda applied as fertilizer, while the soda

accumulates in the soil. Soda and other basic materials tend to correct acidity or to increase alkalinity of soils. Most residues have an effect on soil or crop either beneficial or harmful. Some of these residues are acid and increase the lime requirement; others are alkaline or basic and reduce the need for lime.

Ammoniates—Most of the organic nitrogenous fertilizer materials, as ordinarily used, have no strong tendency toward either acidity or alkalinity.

Cyanamide—Calcium cyanamide, which is listed among the organics, is in a separate class from the standpoint of residual effects. It contains from 10 to 15 per cent of lime (CaO) in addition to the calcium in the cyanamide proper, and so corrects acidity to a considerable extent. This material then may be undesirable in fertilizer for potatoes on soils where potato scab is causing trouble, but yet may be very desirable in small quantities for cauliflower that is growing on somewhat sour soils.

Nitrate of Soda—Crops use the nitrate, leaving soda as a residue in the soil. This is decidedly alkaline and reduces acidity. It, too, may tend to encourage potato scab on neutral soils or those of low acidity. Sodium tends to puddle or break down the granular structure of heavy soils when used in considerable quantities over a period of years. The tilth of sandy soils, however, will not be changed materially by sodium.

Nitrate of Soda-Potash—The effect of this material is similar to that of nitrate of soda but less pro-

nounced, since the potash present is used in plant growth.

Nitrate of Potash—Nitrate of potash has much the same effect as does nitrate of soda-potash but its effect is even less pronounced.

Calcium Nitrate—The effect of calcium nitrate, even though it is neutral, is similar to that of sodium nitrate. Calcium remains in the soil after the nitrate portion has served its purpose in the production of crops. Calcium, like sodium, reduces acidity or increases alkalinity, but, unlike sodium, calcium improves the granulation or tilth of heavy soils.

Sulfate of Ammonia—Crops through the aid of soil bacteria use the nitrogen in the ammonia portion, leaving as a residue the sulfate which forms sulfuric acid (H_2SO_4), and this markedly increases acidity when used in considerable quantity each season over a period of years. This acid is detrimental to lime-loving crops on soils that are not well supplied with lime, but it helps to control potato scab on soils that contain somewhat more lime than is desirable.

Ammonium Chloride—Ammonium chloride, owing to its similar make-up, has the same acidifying effect on the soil as has sulfate of ammonia.

Leunasalpeter, Leunaphos, Nitrophoska—These materials all contain sulfate of ammonia, and so tend to make the soil more acid. The ammonia, nitrate, phosphoric acid, and potash in these materials will be used by the crop.

Ammophos, Ammoniated Superphosphate—Ammophos has essentially the same strong acidifying effect on the soil as does sulfate of ammonia. Pound for pound, the nitrogen in ammoniated superphosphate has the same effect on the soil as does the nitrogen in ammophos. Even though nitrogen is beneficial, its acidifying effect on soils is unavoidable.

Urea—Urea in the soil readily forms ammonium hydroxide (NH_4OH), ammonia (NH_3) + water (H_2O) and carbon dioxide (CO_2). The ammonia is ordinarily changed to nitrate and, in that form, is used by the crop. It is only as the nitrogen in urea is changed to nitric acid, which in turn combines with calcium, magnesium, or other soil bases, that urea may reduce the basic content of the soil. Its acidifying influence, therefore, is the effect, not of any residue from urea, but the usual action of nitrogen, itself, in passing through the necessary chemical changes in order that it may become available to plants.

Uramon—Uramon has essentially the same effect on the soil as does urea.

Ammonium Nitrate—Ammonium nitrate affects the soil in precisely the same way as does urea and to the same extent for each unit of nitrogen that it contains.

Phosphatic Fertilizer Materials—*Rock Phosphate*—Rock phosphate contains lime. The effect of this material, therefore, is to reduce soil acidity rather markedly.

Bone Meal—Bone meal contains much calcium; consequently, its effect is to reduce soil acidity. When used repeatedly in heavy applications for acid-loving plants or shrubs such as rhododendrons, bone meal may change the reaction of the soil so greatly that the plants become unthrifty, and may finally die owing to alkalinity produced by the bone meal.

Superphosphate (Acid Phosphate)—This material has the immediate effect of rendering harmless some factors in the soil called acidity, and so is said to alleviate the effects of acidity; it does not, however, have any marked permanent effect on the soil reaction.

Basic Slag—Basic slag, since it contains calcium and magnesium equivalent to from 30 to 50 per cent of calcium oxide, is decidedly alkaline in its effects. In fact, it has so much lime that it is admittedly used, in part, for the definite purpose of correcting soil acidity. It is an admirable material for use on sour-soil pastures. It should not be used for potatoes on soils having a scab problem, nor in mixed fertilizers.

Phosphate of Potash—In this material both the acid and the base are fertilizer constituents, so there is no residue. It has little effect on the reaction of the soil. It is another ideal material for use when it is best not to change the reaction of the soil.

Potash Fertilizer Materials—Potash fertilizers appear to have little effect on soil reaction.

Muriate of Potash—Muriate of potash consists of potassium used by the plant and the chloride which

forms hydrochloric acid (HCl). Its effect would appear to be that of increasing acidity, but the chlorine washes out and has no material effect on the soil reaction.

Sulfate of Potash—Sulfate of potash acts in the same way as does the muriate. The sulfate from sulfate of potash does not appear to be liberated rapidly enough to be harmful, as is sulfate from sulfate of ammonia.

Sulfate of Potash-Magnesia—Approximately half of this material is sulfate of magnesia, which has little action on the soil, so the effect of this carrier on the reaction is negligible.

Potassium Carbonate—From potassium carbonate plants use the potassium whereas the carbonate part forms carbonic acid and does not permanently influence the reaction of the soil.

Potassium Nitrate—Potassium nitrate has no effect on the reaction of the soil except that of the nitrogen it contains.

Manure Salts and Kainit—These carriers contain varying proportions of muriate and sulphate of potash, and their residues have little effect on soil acidity.

The residual effect of common fertilizer materials on soil reaction is shown in the following tabulation.

EFFECT OF FERTILIZER MATERIAL RESIDUES ON THE REACTION OF THE SOIL

1 *Tend to increase lime requirement*	2 *Tend to decrease lime requirement*
Sulfate of ammonia	Cyanamide
Ammonium chloride	Nitrate of soda
Ammonium nitrate	Nitrate of soda-potash
Ammophos	Calcium nitrate
Leunaphos	Rock phosphate
Leunasalpeter	Bone meal
Nitrophoska	Basic slag
Acidulated fish	
Urea	
Calurea	

The fertilizer materials not shown above have no marked effect on the reaction of the soil or do not tend either to increase or to decrease its lime requirement for crops.

VI

FACTORY-MIXED FERTILIZERS

In the early days mixed fertilizers consisted mainly of animal waste products, such as meat meal, tankage, and bone. Later, bones were treated with acid to increase the availability of the phosphorus. Soon afterwards, deposits of rich phosphatic rock were discovered. This discovery was fortunate, since the supplies of bone were clearly inadequate to meet the rapidly growing demand for phosphorus. It was a short step from treating bone with acid to applying it to ground phosphate rock, which was the beginning of the present important superphosphate industry. In the United States this was in 1852.[1] Nitrate of soda, sulfate of ammonia, and potash salts were added to carriers of phosphorus, making *complete* fertilizers carrying all three fertilizer elements. (The making of mixed fertilizers was begun on a small scale in Baltimore in 1850). *Incomplete* fertilizers are those which do not carry all three elements, such as an 0-10-10 which contains no nitrogen. There was no great change in the fertilizer industry after the discovery of the method of making superphosphate until the introduction

[1] Willett, Herbert, Fertilizer Consumption in the United States, National Fertilizer Association, Washington, D.C., 1937, p. 3.

of the synthetic and chemical fertilizers, such as ammonium nitrate, urea, nitrate of soda, sulfate of ammonia, cyanamide, and nitrophoska. The manufacture of fertilizers has suddenly changed from an industry utilizing mainly waste products to a specialized chemical industry. Consequently the manufacture of fertilizers today is an immense chemical industry in which millions of dollars are invested.

PUBLIC FERTILIZER CONTROL

The first fertilizers consisted mainly of refuse and waste products of the meat packing industry, and from rendering plants. It was at that time that "brand" [2] names came into common use. A grain fertilizer, a so-called "wheat special," probably contained a large proportion of bone, which furnished the crop with a goodly supply of moderately available phosphorus. Another fertilizer made up mainly of tankage with somewhat less bone than the "wheat special" might be called a "vegetable" or "truck special," on the ground that these crops need a higher proportion of nitrogen than do wheat and other grains. As the demand for these fertilizers increased, the supply of high-grade or high-quality goods became inadequate. Inferior or low-grade materials were offered for sale, which on being used failed to give as good results on the crop as the original high-grade fertilizers had done. The fact

[2] "Arm and Hammer" is an old established brand of baking soda and is typical of the use of "brand" names of fertilizer.

that no one could tell a high-grade fertilizer from an inferior one led to a demand for control by the state. This demand came from both the user and the maker of fertilizers and it protects alike the farmer and the reputable manufacturer. The farmer wishes to know more about composition than is expressed in the brand name such as "wheat special." Before purchasing he wishes to know the analysis of the fertilizer. The *analysis* is the statement of the percentage of nitrogen, or of ammonia, of phosphoric acid, and of potash in a mixed fertilizer or in a separate material. Some of the old statements of analyses are unnecessarily complicated, so much so that many farmers are unable to discover the true analysis. The following is a rather confusing statement of fertilizer analysis, but this is more simple than many of them.

GUARANTEED [3] ANALYSIS

	Per cent
Nitrogen	5.0
Equivalent to ammonia	6.08
Phosphoric acid (soluble)	6.0
Phosphoric acid (reverted)	2.0
Available phosphoric acid	10.0
Insoluble phosphoric acid	1.0
Total phosphoric acid	9.0
Potash (water soluble)	5.0
Equivalent to sulfate of potash	9.4

[3] By *guarantee* is meant the manufacturer's warranty that the fertilizer actually contains the plant nutrients represented by the analysis. The term "guaranteed analysis" is often used the same way as guarantee.

What the farmer most needs to know is shown in the preceding tabulation in bold faced type. The bold figures 5-10-5 constitute the *analysis,* or *grade* of this fertilizer. (Five per cent each of total nitrogen and of water-soluble potash and 10 per cent of available phosphoric acid). It is highly desirable for the farmer to know also the proportion of the nitrogen that is supplied as nitrate, that in the ammonia form, and that in organic or some other form. With this information the farmer may choose more intelligently a fertilizer that is suited to his soil and that satisfies the needs of his crops than he can do otherwise. Phosphorus is supplied almost exclusively as superphosphate and potash comes in water-soluble materials. The sources of phosphorus and potash, therefore, are less important than those of nitrogen.

In the United States and internationally the first figure in the analysis is per cent of nitrogen, the second, per cent of phosphoric acid, and the third, per cent of water-soluble potash. In some of the Southern States the first figure formerly represented per cent of phosphoric acid, the second, nitrogen, and the third, potash. Moreover, until very recently, nitrogen was expressed in terms of ammonia in some states. From the standpoint of the fertilizer manufacturer, uniformity throughout the states in the order of stating the percentages of nitrogen, phosphoric acid, and potash in the analysis, as well as all requirements in connection with the statement of materials in mixed goods and all regulations with respect to the fertilizer guarantee is most desirable.

A *low-analysis* fertilizer has long been understood to be one containing fewer than 14 units of plant nutrients; goods having 15 to 23 units were said to be *normal-analysis* fertilizers. A 2-8-2, with a total of 12 units, then is a low-analysis fertilizer, and a 5-8-7 with a total of 20 units is a normal-analysis fertilizer. Ordinary high-analysis goods have 24 to 36 units of plant nutrients. With the new synthetic and the chemically made materials much higher analyses are possible. The term *concentrated* may be used to designate fertilizers which contain a total of more than 36 units of nitrogen, phosphoric acid, and potash.

State control laws in general require the manufacturer to pay an annual license fee or a tonnage tax for each brand, or analysis, of fertilizer which he registers for sale in the state. The regulations require a statement on the bag or on a tag attached to the bag showing:

1. Pounds of actual fertilizer in the bag.
2. Brand, trade-mark, or name of each analysis.
3. Name and address of the manufacturer or the firm marketing the fertilizer.
4. Minimum per cent of nitrogen, or ammonia, of available phosphoric acid, and of water-soluble potash.

The power to enforce the regulations is vested in the state chemist, state department of agriculture, or the state experiment station. Fines may be and sometimes are imposed on manufacturers whose

goods upon analysis by the state's chemist fall below the stated minimum or guaranteed percentage of nitrogen, or ammonia, phosphoric acid, or potash. Many of the states publish a bulletin each year which shows the names of the manufacturers that registered fertilizers in the state for the year, the brands sampled, and the "guaranteed" and "found" analyses. The "guaranteed" is the manufacturer's statement of the minimum percentage of nitrogen, or ammonia, phosphoric acid, and potash present. The "found" analysis is that found by the state chemist upon analysis of samples of fertilizers collected by the state inspectors, who take representative samples of the fertilizers offered for sale throughout the state. These bulletins are available to all citizens of the state and to any others desiring them, in some states upon the payment of a small charge. The farmer may look up a fertilizer offered to him and see whether it was up to or exceeded the guarantee of the previous year. A fertilizer salesman takes pride in showing prospective customers that his company's goods in previous years overran the guarantee, or at least equalled it. The percentages found upon analysis exceed the guarantee much oftener than they fall short of it, which shows that deficiencies are probably due in the main to slight lack of uniformity in mixing. This sort of publicity is probably far more effective than is the imposition of fines.

A typical fertilizer and lime law may be of real interest here.

PROVISIONS OF THE NEW YORK [4] FERTILIZER AND LIME LAW

The statute provides that commercial fertilizer or material to be used as a fertilizer shall be accompanied by or shall have affixed to each and every package, a plainly printed statement which shall certify as follows:

1. The net weight of the contents of the package.

2. The name, brand, or trade-mark under which it is to be sold.

3. The name and principal address of the manufacturer or person responsible for the placing of the commodity upon the market.

4. The minimum per centum of each of the following constituents which may be contained therein:

(a) Nitrogen.

(b) Available phosphoric acid, except that in cases of undissolved bone, basic slag phosphate, wood ashes, untreated phosphate rock, garbage tankage and pulverized natural manures, the minimum per centum of total phosphoric acid may be substituted therefor.

(c) Potash soluble in distilled water.

(d) In the case of ground limestones, marls, mussel shells, and other calcium and magnesium carbonates used for agricultural purposes, the mini-

[4] Relating to Sale and Analysis of Commercial Fertilizers, Circular 507. 1935. Dept. of Agr. and Markets, Peter G. Ten Eyck, Commissioner, Albany, New York.

mum per centum of carbonate, expressed as calcium oxide and magnesium oxide.

(e) In the case of burned and hydrated limes, the minimum per centum of calcium oxide and magnesium oxide.

(f) In the case of other materials containing calcium and magnesium compounds, the minimum per centum of carbonate present, expressed as calcium and magnesium oxide.

If any commercial fertilizer or material to be used as a fertilizer, be sold, offered or exposed for sale in bulk, such printed statement shall accompany every lot and parcel so sold, offered or exposed for sale. That portion of the statement required by this section, relating to the chemical composition of commercial fertilizer or material to be used as a fertilizer, shall be known and recognized as the guaranteed analysis.

The statute further provides that "it shall be a violation of the provisions of this article if the statement required by the last preceding section shall be false in regard to the net weight of the contents of the package sold, offered or exposed for sale, or in the name, brand or trade-mark under which the fertilizer is sold, or in the name and address of the manufacturer or person responsible for placing the commodity upon the market. It shall also be a violation of the provisions of this article if any commercial fertilizer or material to be used as a fertilizer shall contain a smaller percentage of nitrogen, phosphoric acid, potash, calcium oxide or magne-

sium oxide than is certified in said statement to be contained therein."

Prior to May 24, 1923, a deficiency of not to exceed 10 per cent of any of the constituents below the percentage specified upon the label was permitted. An amendment was enacted by the 1923 legislature in New York, effective on the date previously mentioned, eliminating from the statute this provision for tolerance of any deficiency in the guarantee.

In addition to the analysis of fertilizers the farmer needs information as to the materials used in mixtures; in other words, he desires to know the formula. The *formula* is a statement of the materials used and the quantity of each in a ton, in much the same way as a cooking recipe states what and how much of each ingredient should go into a pan of biscuits or a jar of malmalade. Because of the many difficulties involved, the industry has not chosen to state the materials used in mixed goods. There is real need for this information on the part of the buyer of fertilizers, especially as to the ammoniates used, in order that he may select the fertilizer best suited to his crop and soil.. A glance at the list showing the materials tending toward acidity and those tending toward alkalinity indicates clearly the need for such information. (See page 88). Until such time as it may be feasible to make public the formula employed, it would be good practice to use materials like cyanamide and sulfate of ammonia, which neutralize each other to a considerable extent. At times when a unit of nitrogen costs the

manufacturer less in one good ingredient than in any other, it may be expected that the cheaper material will furnish a large part of the nitrogen in the fertilizer after conditioner has been supplied.

Some farmer's co-operatives make so-called "open-formula" fertilizers. That is, they state the exact source of the plant nutrients plainly on the bag or on a tag attached to the fertilizer bag. Some states require the fertilizer manufacturer to state the source of the nitrogen. This information may be helpful to many fertilizer users.

MAKE-UP OF FERTILIZERS

The manufacturer of mixed fertilizers makes or buys superphosphate, obtains potash salts, nitrate of soda, and synthetic ammoniates in part, and obtains fish scrap, tankage, garbage tankage, cottonseed meal, castor meal, and any other materials needed. Leather meal, hair, feathers, wool waste, shoddy, and similar materials may be collected and acidulated. These waste materials may be mixed with sulfuric acid and phosphate rock, forming the so-called "wet base" goods, containing nitrogen and available phosphoric acid. The acid treatment renders the nitrogen in these materials rather readily available to crops, but without acidulation these waste materials are quite useless to plants. It is a service to society for the industry to make good use of these waste materials. The cost of treatment is probably not much below the figure realized for

these materials in mixed fertilizers. If that be true, synthetic ammoniates at prices still lower than at present may soon displace them, except that they are useful as conditioner in mixed goods.

In the factory various materials may be mixed in a more or less moist state. Ammoniates and acid phosphate on mixing undergo chemical reactions that result in lumping or hardening. Curing in the bin or permitting the chemical action to go to completion is necessary in order to produce fertilizers of good drilling quality. The mixture called *base* or *base goods* is reground and mixed with potash, nitrate of soda or sulfate of ammonia, and any other material needed to make up the desired analysis. The whole mass is screened and bagged ready for shipment to the farmer as mixed fertilizer.

The industry can use a large number of ingredients or fertilizer materials in a single mixture. It uses a number of materials which in themselves are perfectly good, yet are not well adapted to home-mixing. This wide range of ingredients contains impurities some of which may supply elements not yet regarded as essential, but which may be of real value to plants. Muck or peat soils are most likely to be deficient in mineral elements which plants need only in very small quantities. It is on peats rather than on mineral soils that the impurities in fertilizer materials may be of greatest service. For this reason, the concentrated fertilizers may not be as useful on peat lands as are ordinary high-analysis goods. Another possible objection to the concen-

trated ones is that farmers have formed the habit of using a certain quantity of fertilizer to the acre, say 200 pounds of 16-per-cent superphosphate on wheat, and they will probably use about that quantity of 40-per-cent superphosphate. One who has been using 1000 pounds of 2-8-10 to the acre for lettuce is in serious, if not certain, danger of trouble should he use instead 1000 pounds of the "double-strength" 4-16-20 on this crop on some old peat lands (Figure 13).

Some care must be exercised in applying the more concentrated goods to be certain that the fertilizer does not come into contact with the seed, because such contact reduces germination and might reduce the yield of the crop. With further development of the synthetic production of ammoniates, and the maunfacture of chemical combinations, like ammophos, and nitrophoska, concentrated fertilizers are a logical result. They are here to stay; it is essential, therefore, that farmers learn how to use them to best advantage.

CONVERSION FACTORS

From what precedes, it is evident that there is a variety of ways of expressing the quantity of various ingredients in fertilizer materials. A tankage, for example, is reported as having a certain percentage of B. P. L. (bone phosphate of lime). In order to learn the percentage of phosphoric acid in the tankage it is necessary to know the relationship between B. P. L. and phosphoric acid. By calculation we

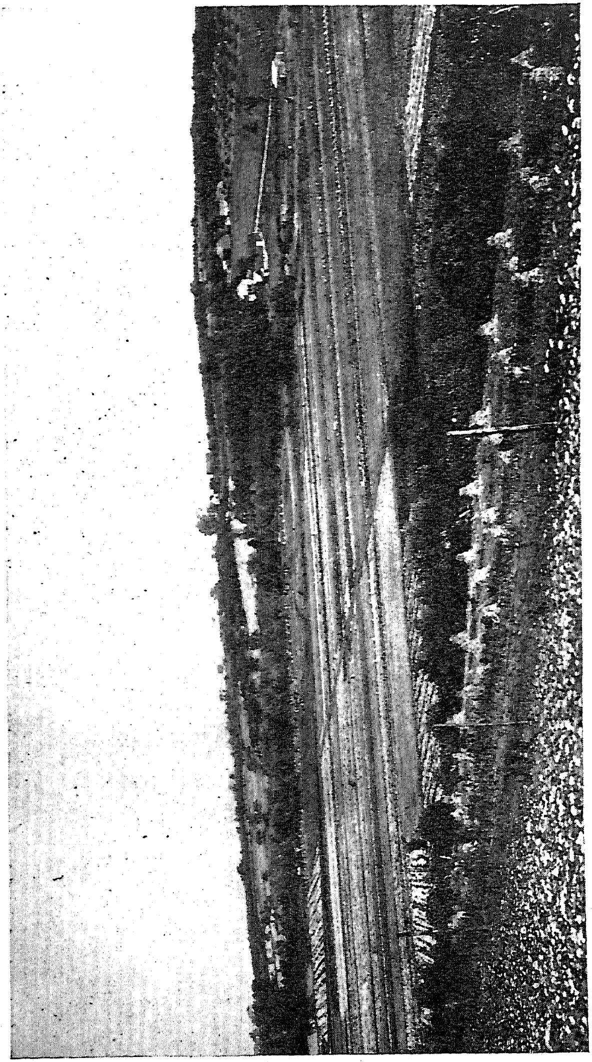


FIGURE 13.—PEAT OR MUCK AREA, WAYNE COUNTY, NEW YORK

The beds in the center are mainly celery, a heavily fertilized crop. (*Courtesy, H. O. Buckman*).

find that phosphoric acid (P_2O_5) is equivalent to 46 per cent of bone phosphate of lime ($Ca_3(PO_4)_2$), or that multiplying the percentage of B. P. L. by 0.46 gives the percentage of phosphoric acid. Example: a tankage is quoted as having 20% B. P. L. How much phosphoric acid has it? 20% B. P. L. $\times$ 0.46 = 9.2% P_2O_5. The tankage contains 9.2 per cent of phosphoric acid.

Table IX gives the figures for converting or changing percentages of various fertilizer terms or expressions into their equivalents and should be useful in this connection.

TABLE IX—CONVERSION TABLE

Given per cent as	*To find per cent as*	*Multiply by*
Ammonia NH_3	Nitrogen N	0.8225
Nitrogen N	Ammonia NH_3	1.216
Bone phosphate of lime $Ca_3(PO_4)_2$	Phosphoric acid P_2O_5	0.46
Phosphoric acid P_2O_5	Phosphorus P	0.437
Phosphoric acid P_2O_5	Bone phosphate of lime $Ca_3(PO_4)_2$	2.20
Phosphorus P	Phosphoric acid P_2O_5	2.29
Phosphorus P	Bone phosphate of lime $Ca_3(PO_4)_2$	5.00
Potash K_2O	Potassium K	0.83
Potash K_2O	Muriate of potash KCl	1.60
Potassium K	Potash K_2O	1.20
Potassium K	Muriate of potash KCl.	1.85
Muriate of potash or Potassium chloride KCl.	Potash K_2O	.625

VII

HOME-MIXING OF FERTILIZERS

THE one really important factor in the value of a fertilizer is the chemical form and availability of plant nutrients in the materials composing the mixture. Given high-grade available fertilizer materials, a first class fertilizer can be mixed satisfactorily either on the barn floor or in the well-equipped factory. There should be no appreciable difference in value if equally good materials are used in both methods of mixing.

Home-mixing has a distinct educational value. One who mixes his own fertilizers becomes familiar with the materials of which they are made. He studies his soils, his crop needs, the comparative availability of different ammoniates, for example, nitrate of soda or urea compared with garbage tankage, and the residual effects of different fertilizer materials on soil acidity or alkalinity.

POINTS NEEDING CONSIDERATION

Effect on Soil Acidity—The list at the end of Chapter V shows the effect of different fertilizer ingredients or the residues from them on the reaction of the soil. It is often necessary to consider the sen-

sitiveness of the crop and the reaction of the soil. Lettuce is very sensitive to high acidity. It would, therefore, involve real risk to use a fertilizer for this crop that is made up of acid materials including much sulfate of ammonia on unlimed sour land.

Open-formula fertilizers enable the farmer to know whether the mixtures offered fit his crop and soil conditions. It would be highly desirable if manufacturers would state on the tag the sources of nitrogen in a fertilizer. Specific instances will show how residual effects may be the determining factor in selecting fertilizer materials. Cauliflower, for example, a crop sensitive to acid, is to be grown on a sour mineral soil in a locality where lime is expensive. One would use as much as possible of materials which tend to decrease acidity (column 2, p. 88) and of those that do not affect the reaction of the soil, provided that this choice of materials does not greatly increase costs. On the other hand, a potato farmer who is troubled with scab injury will select most of his materials from those tending toward acidity (column 1, p. 88) in order to control scab.

Satisfactory Uniformity Possible—That factory-mixed goods are not always entirely uniform in composition is shown by a few instances of the "found" analysis being slightly below the "guaranteed" analysis, as reported in the various state fertilizer control bulletins. This is no reflection on the integrity of the manufacturer, but shows merely a slight lack of absolute uniformity in the mixture.

Real uniformity in home-made mixtures can be attained but the benefits therefrom are slight. Obtaining true uniformity in such mixtures adds too much to the cost. Work at the South Carolina station indicates that shoveling three times gives a mixture of satisfactory uniformity. This is shown in Table X.

TABLE X—UNIFORMITY OF HOME-MIXED FERTILIZERS [1]

	Pounds of ammonia	*Pounds of phosphoric acid*	*Pounds of water-soluble potash*
According to calculation the mixture contained	2.58	11.84	3.00
Found by analysis	2.76	11.77	3.01

[1] Keitt, T. E., "Chemistry of Farm Practice," Wiley and Sons, N. Y., Page 164, 1917.

Greater uniformity than this might be attained by further shoveling or by mixing with machinery, but this mixture gives excellent results in the form of increased crop yields.

A 10-20-10 fertilizer was mixed in 1937 by a class in soils and fertilizers at Cornell University by shoveling three times and then passing it through a screen of about three meshes to the inch. Upon analysis the mixture was found to contain 10.1 per cent of nitrogen. This indicates that a perfectly satisfactory mixture was made in this manner.

Availability of Materials—Another important factor in the selection of materials is their relative availability. The accompanying list gives in general

the relative availability of fertilizer materials, the more available being placed at the upper end of the columns.

AVAILABILITY OF FERTILIZER MATERIALS

Carriers of:

Nitrogen	*Phosphoric acid*
Nitrate of soda	Ammophos
Nitrate of potash	Potassium phosphate
Nitrate of lime	Nitrophoska
Nitrate of soda-potash	Superphosphate
Nitrophoska	Basic slag
Ammonium nitrate	Bone meal
Leunasalpeter	Rock phosphate
Cal-Nitro	
Urea, Calurea, Uramon	
Ammophos	
Sulfate of ammonia	
Cyanamide	
Animal tankages	
Dried ground fish	
Vegetable materials	
Hair, leather, woolwaste, etc. (untreated.)	

All of the potash salts are soluble in water and consequently are of practically the same ready availability.

There are two principal reasons for not mixing certain materials. Any form of lime, or cyanamide, or basic slag should not be mixed with superphosphate, since lime reduces the percentage of readily available phosphoric acid. Neither should these same lime-carrying materials be mixed with sulfate of ammonia, the leuna salts, ammophos, or urea, since lime may cause loss of ammonia.

Deliquescent Materials—Certain materials take up moisture from the air more readily than others, or are said to be deliquescent. Among these more deliquescent materials are nitrate of soda, nitrate of lime, nitrate of potash, and ammonium nitrate, together with kainit and manure salts, which contain common salt or sodium chloride ($NaCl$).

Absorbent Materials—Drier or conditioner is needed to counteract the tendency to become moist which causes the mixture to lump or harden. The organic ammoniates, dried blood, animal tankage, dried ground fish, garbage, and nitrogenous tankage, cottonseed meal, cocoa, linseed meal, castor meal, and cyanamide are all good driers. Cyanamide is classed as organic because of its carbon, even though it is made synthetically. Two to three hundred pounds of good drier to the ton are usually ample to keep a mixture in perfect drilling condition. Less drier is needed if only small quantities of deliquescent materials are used in mixtures. Drier may be omitted if the fertilizer is to be applied immediately after mixing. Omitting drier makes possible a considerable saving in cost of ammoniates. Less drier is needed in mixtures that contain ammoniated superphosphate than in the old-type materials.

Filler not Needed—With home-mixed goods it is not necessary that the formula make an exact ton. Suppose all the nutrients for a ton of a given analysis make 1750 pounds instead of 2000. Filler or "make-weight" need not be added to complete the ton, but

instead the drill may be set to sow 175 instead of 200 pounds, or 875 instead of 1000 pounds to the acre, since 875 pounds contains the same quantity of plant nutrients as do 1000 pounds of the ordinary mixture.

Steps in Home-Mixing—A concrete example may explain how home-mixing can be or is being done. It may show some advantages and indicate the possible financial saving.

Choice of Materials—A Long Island farmer plans to plant 24 acres of potatoes and to fertilize them with 2500 pounds of 5-10-5 to the acre. He will need, therefore, 30 tons of this mixture. Scab has been more or less troublesome. He has no green material to turn under and does not wish to use sulfur for increasing acidity to the point of controlling scab. He consults the reaction chart on page 88 and finds that sulfate of ammonia has a distinct acid tendency, so he will use it to help control scab. He will plant early potatoes, so he feels that some nitrate should be used. Nitrate of soda is chosen in spite of its alkaline residue which, however, is neutralized by the sulfate of ammonia.

Formula with Drier—As early potatoes in that section must be planted as soon as weather conditions permit, the fertilizer, if home-mixed, must be taken care of during the winter, when labor is not gainfully employed. Dried ground fish is selected as drier, and 16-per-cent superphosphate and muriate of potash to supply phosphoric acid and

potash. The farmer must now calculate how much of each ingredient to use.

Table XI gives the composition of the more important fertilizer materials.

TABLE XI—COMPOSITION OF FERTILIZER MATERIALS

Material	*Nitrogen per cent*	*Nitrogen equivalent to ammonia per cent*	*Phosphoric acid per cent*	*Potash per cent*
Nitrate of soda	16	19.45	...	...
Nitrate of lime	15	18.2	...	...
Cal-Nitro	16.0	19.45	...	...
	20.5	25.00	...	...
Leunasalpeter	26.0	31.6	...	...
Potassium nitrate	13	15.8	...	45
Sulfate of ammonia	20.5	25	...	...
Urea	46.0	55.9	...	...
Uramon	42.0	51.0	...	...
Calurea	34.0	41.3	...	...
Cottonseed meal	6.6	8	2–3	1–2
Castor meal	5.8	7	1	1
Tobacco stems	1.2–3.3	1.5–4	...	4–9
Cyanamide	22.0	26.7	...	...
Animal tankage	8.2	10	8	...
Animal tankage	5.0	6.01	10	...
Dried ground fish	8.2	10	6	...
Ammophos	11	13.4	48	...
Ammophos	16	19.45	20	...
Superphosphate (acid phosphate)	...	...	16	...
	...	...	20	...
	...	...	32	...
	...	...	40	...

(*Continued on next page*)

Material	*Nitrogen per cent*	*Nitrogen equivalent to ammonia per cent*	*Phosphoric acid per cent*	*Potash per cent*
Bone meal (steamed)	2.5	3	24	...
Basic slag	...	...	13	...
Muriate of potash	...	...	...	50–60
Sulfate of potash	...	...	...	50
Sulfate of potash-magnesia	...	...	...	25
Manure salts	...	...	...	20–30
Kainit	...	...	...	14–20

Determining Quantity of Materials Needed— Table XII shows the weight of materials required to supply one unit of plant nutrients.

TABLE XII—WEIGHT REQUIRED TO SUPPLY A UNIT OF PLANT NUTRIENTS

Fertilizer Material	*Nitrogen pounds*	*Ammonia pounds*	*Phosphoric acid pounds*	*Potash pounds*
Nitrate of soda	125	103	...	...
Nitrate of lime	133	110	...	...
Cal-nitro 16.0	125	103	...	...
Cal-nitro 20.5	98	80	...	...
Leunasalpeter	77	64	...	...
Potassium nitrate	154	187	...	44.5
Sulfate of ammonia	98	80	...	...
Urea	44	36	...	...
Uramon	48	40	...	...
Calurea	59	48.5	...	...
Cottonseed meal	303	250	...	...
Castor meal	346	286	...	...

Fertilizer Material	*Nitrogen pounds*	*Ammonia pounds*	*Phosphoric acid pounds*	*Potash pounds*
Tobacco stems 3%	667	548	...	400
Cyanamide	91	75	...	...
Animal tankage 8.2%	244	200	...	...
Animal tankage 5%	400	333	...	...
Dried ground fish 8.2%	244	200	...	...
Ammophos (11-48)	182	150	42	...
Ammophos (16-20)	125	103	100	...
Superphosphate (acid phosphate) 16%	...	...	125	...
Superphosphate (acid phosphate) 20%	...	...	100	...
Superphosphate 32%	...	...	62.5	...
Superphosphate (acid phosphate) 40%	...	...	50	...
Basic slag 13%	...	...	154	...
Muriate of potash 50%	...	...	...	40
Muriate of potash 60%	...	...	...	33
Sulfate of potash 50%	...	...	...	40
Sulfate of potash-magnesia 25%	...	...	...	80
Manure salts 20%	...	...	...	100
Kainit 14%	...	...	...	143

The quantities required for a unit are based on the compositions shown in Table XI. From these weights required for one unit it is easy to find the weight needed for any desired number of units. It seems best to figure out first how many pounds of each ingredient is needed for a ton. It will be recalled that these figures, 5-10-5, mean per cent or

pounds in one hundred; a ton, being 20 hundreds, will have 5x20 or 100 pounds each of nitrogen and potash and 10x20 or 200 pounds of phosphoric acid. The farmer decides to use 100 pounds of nitrate of soda and 400 pounds of animal tankage. We will now set these down in Table XIII and show what nutrients each supplies.

TABLE XIII—MAKE-UP OF A TON OF 5-10-5 FERTILIZER

Ingredients	*Nitrogen pounds*	*Phosphoric acid pounds*	*Potash pounds*	*Required for a ton pounds*	*Cost of ingredients*
100 lbs. nitrate of soda ...	16	...	...	N	$1.80
400 lbs. animal tankage, 8.2% N..	33	...	...	100	9.40
250 lbs. sulfate of ammonia	51	...	...		4.13
1000 lbs. 20% superphosphate ..	...	200	...	P_2O_5 200	10.00
167 lbs. 60% muriate of potash	...	...	100	K_2O 100	3.34
1917 lbs. total	100	200	100	...	$28.67

See note on page 121.

The following were used as representing current cash retail prices. These are subject to change, especially the ammoniates, which, owing to severe competition, have recently changed markedly; 5-10-5 mixed fertilizer $34.00 a ton, nitrate of soda $36.00, sulfate of ammonia $36.00, animal tankage, 8.2% nitrogen, $47.00, muriate of potash 60%, $47.00, and 20-per-cent superphosphate (bulk) $20 a ton.

One hundred pounds of nitrate of soda supplies 16 pounds of nitrogen, 400 pounds of animal tankage gives $4 \times 8.2 = 33$ pounds of nitrogen. One hundred pounds of nitrogen are required for a ton of 5-10-5. The nitrate of soda and tankage furnish $16 + 33$ or 49 pounds of nitrogen. Then 100 pounds -49 leaves 51 pounds of nitrogen to be supplied by sulfate of ammonia. Sulfate of ammonia has 20.5 pounds nitrogen in 100 pounds; therefore, as many hundreds are required as 20.5 will go times into 51. By division ($51 \div 20.5$) this is found to be 2.5 hundreds, or $2.5 \times 100 = 250$ pounds of sulfate of ammonia required.

As shown in Table XIII, 200 pounds of phosphoric acid are required for a ton of 5-10-5 fertilizer. This is to be obtained from 20-per-cent superphosphate. Then as above, $200 \div 20 = 10$, or $10 \times 100 = 1000$ pounds of superphosphate required.

One hundred pounds of actual potash are required in a ton of 5-10-5. Accordingly 100 pounds are to be supplied by muriate of potash, which contains 60 pounds actual potash in each 100 pounds. So $100 \div 60 = 1\frac{2}{3}$ hundreds, or $1\frac{2}{3} \times 100 = 167$ pounds of muriate of potash required.

Thus these five ingredients furnish the nutrients needed for a ton of 5-10-5. Upon totalling it is found that 1917 pounds of fertilizer materials supply the plant-nutrient equivalent of a ton of 5-10-5. We can add 83 pounds of filler or "makeweight," but it saves time and labor to use 1917

pounds (1900 pounds for all practical purposes) rather than 2000 pounds (required if filler is used) because 1917 pounds of this home-made mixture supply the crop with all of the plant nutrients which the crop could have obtained from 2000 pounds of a regular 5-10-5 fertilizer. In fact, this mixture is essentially one-twentieth more concentrated than a regular 5-10-5 fertilizer. Since the 1917 pounds supply the equivalent of a ton and 30 tons were needed we still need to order 30 times 100 pounds of nitrate of soda, or 3000 pounds, and other ingredients in proportion as shown below.

The complete requirement will then be:

30 x	100 lbs.	or	3,000 lbs.	sodium nitrate.
30 x	400 lbs.	or	12,000 lbs.	animal tankage.
30 x	250 lbs.	or	7,500 lbs.	sulfate of ammonia.
30 x	1000 lbs.	or	30,000 lbs.	superphosphate.
30 x	167 lbs.	or	5,000 lbs.	muriate of potash.

This is a total of 57,500 pounds or 28.75 tons, or a medium-sized car load. It may be well to adjust the quantity of each material to the nearest even bag of the desired size.

Purchase of Materials—The next step is to obtain quotations on this bill of material to be delivered by one fertilizer company as an assorted car. The goods are ordered, received, paid for, and hauled to the farm.

The Actual Mixing—A fairly smooth tight plank or concrete floor is needed for the mixing. If none is available, a tight floor may be made from a good

grade of flooring lumber. Twelve by 16 feet with side walls 2 to 3 feet high is a good size. A wooden or concrete floor is preferable, but a smooth, hard, dry dirt floor is satisfactory. A scale, screen, shovels, and hoes or rakes are needed. The screen may be of half-inch hardware cloth similar to a sand screen. It is convenient to mix a ton or two at a time. The weights on the original bags are sufficiently accurate for estimating the quantity needed, and little weighing of the materials before mixing is necessary. A common procedure is to spread out at one end of the floor one-half of the superphosphate, and about half of each of the other ingredients—leveling with the hoe, rake, or shovel after each is laid down—then to put on the rest of the superphosphate and of each ingredient in the same order as before. Now turn the materials by hand with a shovel in one direction, and if desired back in the other as in mixing the ingredients for concrete. The screen may be set up as for sand, at an angle of about 30 degrees, and the mixture put through it. Any lumps that roll off the screen are crushed and put through it. After another shoveling like the first, the mass is mixed sufficiently and ready for bagging. The scale may be used so as to put the desired quantity into each bag. The fertilizer may be put back into the original bags which will hold it when mixed, if the bags are filled to the same weight as before. Two men may mix and bag six to eight tons a day at a labor cost during the off-season of about $1 a ton.

By reference to Table XIII it is noted that the

ingredients for the 5-10-5 fertilizer cost $28.67. Adding $1 a ton for mixing makes the total cost $29.67, the ready-mixed goods cost about $34.00. The difference is $4.33 a ton. On the equivalent of 30 tons the saving is $130.00. From these figures it is perhaps not certain that home-mixing always pays. Another point worthy of consideration, however, is that there is somewhat less material to haul and spread than when using the regular factory-mixed 5-10-5 fertilizer. Saving in cost is but one of the many factors to be considered before deciding whether to home-mix or to purchase fertilizers ready-mixed.

Formula without Drier—As previously pointed out the organic ammoniates are rather expensive but necessary for drier when mixing is done a considerable time in advance of sowing. Fertilizer mixed without drier ordinarily will lump in storage, so it should be used soon after mixing. With midseason crops such as late potatoes even where these are grown on a considerable scale, 10 to 20 acres on a farm, time may be taken to mix the fertilizer as applied, since there is a much longer period over which late potatoes may be planted as compared with early ones. By doing this one can eliminate the expensive drier and use only the less expensive concentrated ammoniates. This is being done on New York potato farms. If a very large acreage of late potatoes is to be planted, it may be preferable to mix a part of the fertilizer in advance of seeding time.

Let us plan for mixing a 5-10-5 as above, using sulfate of ammonia, 20-per-cent superphosphate, and muriate of potash. This makes the determination of quantity of each ingredient very simple. As before, 5x20 or 100 pounds of nitrogen are required, 200 pounds of phosphoric acid, and 100 pounds of potash in a ton. The quantities of materials required are given in Table XIV.

TABLE XIV—QUANTITIES OF MATERIALS REQUIRED

	Cost of ingredients
100 lbs. nitrogen ÷ 20.5 (%N) 488 lbs. sulfate of ammonia	$ 8.05
200 lbs. phosphoric acid ÷ 20 (% P_2O_5) 1000 lbs. superphosphate (bulk)	10.00
100 lbs. potash ÷ 60 (% K_2O) 167 lbs. muriate of potash	3.34
Total 1655 lbs.	$21.39

It is clear that this mixture is nearly one-fifth more concentrated than ordinary 5-10-5, or in other words that 1655 pounds supply plant nutrients fully equivalent to a ton of commercial 5-10-5. The real analysis of this mixture is 6-12-6, one-fifth more than 5-10-5, or a total of 24 units of plant nutrients, truly a good high-analysis fertilizer which serves admirably the purpose for which it was mixed. Equivalent quantities of this mixture as compared with a regular 5-10-5 are shown here.

400 lbs. of this mixture are equivalent to 480 lbs. of 5-10-5
800 lbs. of this mixture are equivalent to 960 lbs. of 5-10-5
2000 lbs. of this mixture are equivalent to 2400 lbs. of 5-10-5

The ingredients in this mixture cost $21.39 for the equivalent of a 5-10-5 fertilizer, and the materials are definitely suited to crop and soil needs. The spreading requires more time than mixing; hence $1 a ton is probably about the right charge for actual mixing. Total cost therefore is $22.39 a ton, or there is a saving of $11.61 a ton. The saving therefore on the equivalent of 30 tons is $348.00.

Farmers today are mixing fertilizer such as this in a good wagon box and applying it broadcast at once with a lime drill. One man does chores and mixes and spreads three tons a day in this way.

Occasionally a farmer mixes fertilizer in the drill at planting time. This does not give a uniform mixture. Mixing before putting into the drill is preferable.

The following formulas may be suggestive for home-mixing:

5-10-5

With drier Pounds		*Without drier* Pounds
300	tankage or fish 8% N	...
100	nitrate of soda 16% N	100
300	sulfate of ammonia 20.5% N	410
1000	superphosphate 20%	1000
167	muriate of potash 60%	167
1867		1677

5-8-7

300	tankage or fish 8% N	...
100	nitrate of soda 16%	100
300	sulfate of ammonia 20.5%	410
800	superphosphate 20%	800
233	muriate of potash 60%	233
1733		1543

With drier Pounds	4-16-4	Without drier Pounds
250	tankage 5% N	...
100	nitrate of soda 16% N	100
251	sulfate of ammonia 20.5% N	312
240	superphosphate 20%	320
680	superphosphate 40%	640
400	manure salts 20%	400
1721		1772

	5-20-5	
300	tankage 8% N	...
100	nitrate of soda 16% N	100
300	sulfate of ammonia 20.5% N	410
1000	superphosphate 40%	1000
167	muriate of potash 60%	167
1867		1677

	10-20-10	
250	tankage or fish 8% N	...
391	urea 46% N	435
1000	superphosphate 40%	1000
333	muriate of potash 60%	333
1974		1768

These formulas are sufficient to show how high-analysis fertilizers as well as concentrated mixtures may be made from a small number of ingredients, either with or without drier. Castor meal may be used in place of 5-per-cent tankage as conditioner; one might then use somewhat less of the more concentrated ammoniates.

Advantages of Home-Mixing—One of the advantages of home-mixing is the saving on the labor cost of mixing, bagging, and somewhat on other necessary expenses. It is clear that the wages of city labor during a rush such as the heavy fertilizer shipping season, when the plant is being operated during two or perhaps three shifts, is much higher than on the farm during a dull season such as winter or early spring. In fact, labor on some farms growing mainly potatoes, onions, celery, and other heavily fertilized crops may be practically unemployed at that season, so it might be fair to make almost no labor charge for the work of mixing fertilizers on the farm during winter or early spring.

It is always advantageous for farmers who market their own products wholesale to co-operate on their purchases of fertilizer in order to get some advantages of buying wholesale. One farmer operating an extensive area may obtain these advantages individually, but for the majority of farmers it is necessary to work together, pooling orders so that the fertilizer materials may be delivered to each railroad station in full carloads in so far as possible. Only in this manner can the lowest possible price on fertilizers be obtained. Pooling of orders applies in a similar way and with as good results proportionately in the purchase of ready-mixed fertilizers.

Possible Disadvantages—There may be some disadvantages in home-mixing. Finding a good dry place in which to store the fertilizer after it is mixed often presents some difficulties. Also, it is not al-

ways easy to obtain the necessary ingredients, especially for the farmer who uses only a few tons of fertilizer a year, unless he can buy materials in a pool with neighbors. It is easier to purchase ready-mixed goods, but it does appear that the advantages of home-mixing are worthy of serious consideration by many farmers who use more than ten tons of fertilizer each year.

NOTE.—Because of the wide fluctuations in prices of fertilizer materials and of ready-mixed fertilizers and also in labor costs, the financial calculations with respect to the advantages of home mixing have not been adjusted to current levels. Moreover, the materials needed for home mixing may not be readily obtainable during the war. In general, however, the saving from home mixing is probably as great, if not greater, than before the war.

VIII

PURCHASE AND USE OF FERTILIZERS

PURCHASE OF FERTILIZER

Good farmers should purchase fertilizers on a cash basis. The cost of fertilizer credit is high, partly because of a few bills that cannot be collected. Fertilizer credit is different from credit on a mower or a plow. Once fertilizer has been applied to the land it is gone as far as the dealer is concerned. In the event payment is not made, the dealer cannot go out and get fertilizer; if a farmer defaults on payments for machinery, however, the dealer may take it back. Fertilizer credit is granted on the basis of the dealer's faith in the buyer's intention to pay and in the belief that he can use the fertilizer to good advantage which will enable him to pay for it. The question of the buyer's good intentions should not be open to discussion, but drought, floods, sickness, frost, or accidents may make payment utterly impossible. These factors combine to make the cost of fertilizer credit equivalent to from 12 to 17 per cent annual interest. Supplying credit is the main business of banks, and they rather than the fertilizer manufacturer or dealer should furnish it. It seems clear that it would be very profitable for a farmer

to borrow money from the bank at 6 per cent for a short time in order to avoid payment of from 12 to 17 per cent interest on the fertilizer. The industry itself recognizes the advantage of prompt payment and encourages it by rather liberal cash discounts. Well-established dealers do not always encourage cash payment, and some of them grant no cash discount. This is discouraging to the careful business farmer who sees the need of reducing costs by paying cash. He, very probably, purchases other necessities where the value of cash payment is recognized by a fair discount. Buying together by a group of farmers, whether it be mixed goods or separate materials for home-mixing, is good practice. The purchase usually for cash may be and often is made through the regular local dealer.

THE USE OF FERTILIZERS

In Extensive Farming—In the more extensive forms of agriculture fertilizers are used to supplement the nutrients that the crop can get from the soil. This will necessarily mean moderate quantities to the acre for grain and hay crops. For a four-year rotation of corn, small grain, clover, and timothy, 250 to 300 pounds to the acre of 20-per-cent superphosphate or its equivalent in 32- or 40-per-cent superphosphate, applied on both corn and grain, is often the most economical fertilization. There are, however, numerous instances, especially should the cost of nitrogen in mixed goods be mate-

rially reduced, where a similar, or larger, quantity of a mixed fertilizer may be profitable. Such fertilizer for feed crops should be high in phosphoric acid, with a moderate percentage of ammonia and perhaps potash, too, where no manure is used directly for the fertilized crop, or if the manure is used on the new seeding or on timothy. Both of them are good places for manure.

It should be borne in mind that the crop for which fertilizer is applied does not use all of it. One-third to one-half of the fertilizer may remain in the soil for the benefit of succeeding crops. Nitrogen used in small quantities, especially on light soils, is an exception to this statement, since it is either used by the crop or lost from the soil before another crop is planted. Because of this carrying over of plant nutrients, we should consider fertilizing the whole rotation of feed crops, such as corn, oats, clover, and timothy, rather than fertilizing the individual crop, such as corn or wheat. The suggestion (p. 123) of 300 pounds to the acre on both corn and grain assumes that sufficient phosphoric acid remains in the soil to supply the clover and timothy crops reasonably well. There is little question but that a higher percentage of potash than is economical is used for grain crops on medium to heavy soils when the mixture contains 8 to 10 per cent of potash, especially on manured land.

In Intensive Farming—In intensive farming where fertilizer such as 5-10-5 is used at the rate of 1000 to 3000 pounds to the acre, the crop does not

use all of the plant nutrients during the season in which they are applied. This high rate of application is for crops that yield on the average a large gross cash return to the acre, such as celery, lettuce, onions, potatoes, cauliflower, or other vegetables.

The effect of residues was considered fully in Chapter V, and should have careful attention in this connection. The value and effect of fertilizer carrying over from preceding crops is sometimes important, especially on peat soils. An extreme case may be cited. Celery was grown under glass. A mixed fertilizer was used before planting, a certain quantity being used for each 3 x 6-foot sash; later nitrate of soda and, still later, tankage were added. The total fertilizer used was at the rate of more than 10,000 pounds, or five tons, to the acre. The celery made a good crop. It was followed by lettuce, which received no fertilizer. The lettuce was yellow, plainly abnormal, suffering from an excess of soluble plant nutrients. The lettuce crop was a failure. The large residue of potash was probably an important detrimental factor for the lettuce crop, which is especially sensitive to an over-supply of soluble potassium.

On some New York peat or muck soils, at least during certain seasons and under certain climatic conditions, lettuce makes an unhealthy growth following crops which received a ton or more to the acre of fertilizer containing 20 units of plant nutrients. The grower should study his soil with care, since peat soils vary widely within short distances.

Areas separated by only a narrow strip of mineral soil may be so different that lettuce on them does not respond in the same way to the same fertilizer treatment.

FIGURE 14.—CELERY GROWN ON PEAT, WAYNE COUNTY, NEW YORK

Celery is heavily fertilized. (*Courtesy, U. S. Dept. of Agriculture*).

Quantity of Plant Nutrients—Too often farmers apply a given quantity of a fertilizer to the acre without much consideration of the quantity of plant nutrients the crop needs or can use with profit to the farmer. He should decide, with such information as is available, how much nitrogen, phosphoric acid, and potash is likely to be most economical for

potatoes on Long Island, in Maine, or on the hills of New York and Pennsylvania, for onions or tobacco in the Connecticut Valley, or for cotton in Georgia, and then use separate carriers or mixed

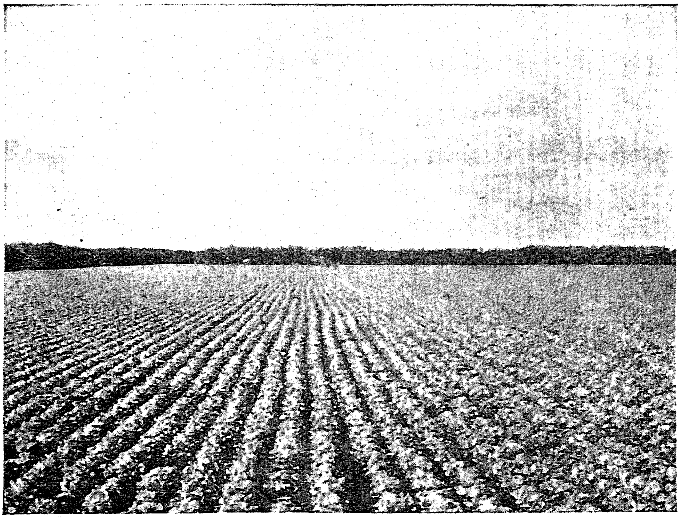


FIGURE 15.—LETTUCE ON PEAT, GENESEE COUNTY, NEW YORK

—Lettuce being a sensitive crop requires careful fertilization.

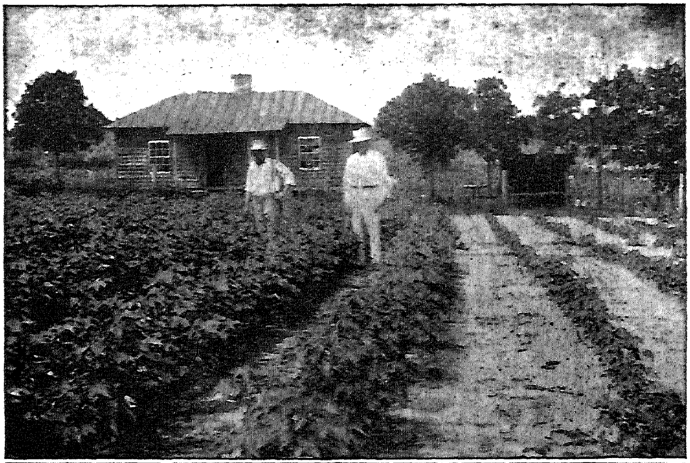
goods to supply approximately that quantity of plant nutrients to the acre.

Low- or High-Analysis, or Concentrated Fertilizers—Low-analysis fertilizers (fewer than 14 units) are made up either of low-grade materials or carry a considerable weight of filler in each ton. A 2-8-2, for example, can be made up of sulfate of ammonia,

20-per-cent superphosphate, and 50-per-cent muriate of potash, and weigh but 1040 pounds. When a whole ton is required to carry the nutrients of a 2-8-2, a low-grade tankage, probably garbage tankage, without any high-grade ammoniate, and kainit, instead of muriate, are probably used. Such a low-analysis fertilizer has two disadvantages: firstly, one must pay freight on and handle a bulky product with filler or one made up of low-grade materials, and secondly, low-grade materials are usually low in availability. Under the latter conditions the fertilizer is of less real value to crops and it is always more expensive than is a high-analysis mixture.

It costs the same to mix, bag, haul by freight, or by wagon or truck, and to spread a fertilizer whether it carries 12 or 24 units of plant nutrients. The latter will be made up by using ammoniates of higher quality than the low-analysis goods.

Of the usual analyses, the higher ones should be considered. A 4-8-4 and 5-10-5 are good examples. The relationship between nitrogen, phosphoric acid, and potash is the same in both; each has twice the percentage of phosphoric acid as of nitrogen or potash, and may be considered as a multiple of a 1-2-1 ratio. One ton of 4-8-4 and 1600 pounds of 5-10-5 have the same content of plant nutrients. Where a ton of 4-8-4 (4 x 20) has 80 pounds each of nitrogen and potash, 1600 pounds of 5-10-5 (5 x 16) has 80 pounds each of nitrogen and potash. It is clear, therefore, that the 5-10-5 has one-fourth more plant nutrients to the ton than has the 4-8-4.



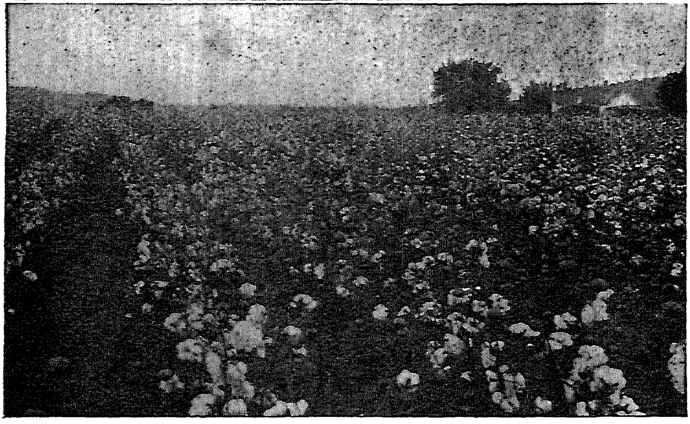


FIGURE 16.—(*Upper*) COTTON ON NORFOLK SAND

At right, no fertilizer, at left 1000 pounds of 6-8-4 used to the acre. (*Courtesy, Agronomy Department, South Carolina Agr. Exp. Station*).

FIGURE 17.—(*Lower*) COTTON READY TO HARVEST, ROME, GEORGIA

This cotton received an application of 500 pounds to the acre of a 5-15-5 fertilizer. (*Courtesy, W. H. Sachs*).

Consequently by purchasing the higher-analysis fertilizer one saves one-fourth of the freight, bagging, hauling, and spreading expenses, and at the same time obtains a material of somewhat higher value. During the past several years the saving by using 5-10-5 instead of 4-8-4 has been approximately 8 per cent.

High-analysis fertilizers such as 6-12-6, 8-16-8, or 10-20-10 can be made up on this 1-2-1 ratio. This necessitates the use of such concentrated materials as urea, nitrophoska, and double superphosphate. The concentrated ones of lower analyses can be made of less concentrated fertilizer materials.

How Soil Affects Choice of Fertilizer—A few points about soils may aid in selecting a fertilizer to fit the soil. Dark colored soils are usually well supplied with organic matter and consequently with nitrogen, which is usually sufficient for grain and forage crops. Vegetable and other cash crops, however, often need additions of nitrogen even on dark colored soils.

Most soils are deficient in available phosphoric acid for vegetable and cash crops and sometimes for grain also. Nearly all sandy and gravelly soils are very low in potash and most crops on such soils if unmanured respond to potash in the fertilizer. The heavier mineral soils usually contain large supplies of total potash. If manure is used and clover is grown in a short rotation ample potash becomes available for grain and hay crops, but usually not enough for vegetables in general. Muck or peat soils are

FIGURE 18.—(*Upper*) BEETS GROWN WITHOUT FERTILIZER

FIGURE 19.—(*Lower*) BEETS FERTILIZED

Grown with 300 pounds of 0-12-12 and 150 pounds of nitrate of soda to the acre at planting time. (*Courtesy, Dept. of Soils, Michigan Agr. Exp. Station*).

FIGURE 20.—(*Upper*) TOBACCO, UNFERTILIZED, KENTUCKY

Yield, 575 pounds to the acre.

FIGURE 21.—(*Lower*) TOBACCO, FERTILIZED, KENTUCKY

Yield, 1625 pounds to the acre. One hundred pounds of nitrate of soda, 600 of superphosphate, and 300 pounds of sulfate of potash were used to the acre. This is equivalent to 1000 pounds of approximately 1-9-14 to the acre in 4 years. (*Courtesy, Agronomy Department, Kentucky Agr. Exp. Station*).

deficient in potash for nearly all crops except grasses. Both mineral and muck soils if unmanured need additions of potash for vegetable crops. Whenever it is convenient to determine whether the soil needs lime or naturally contains it, some effort should be made to fit the fertilizer to the soil reaction. Reference to the list on p. 88, showing the effect of fertilizer materials on the reaction of the soil, will be an aid in this connection.

Fertilizer Needs of Different Types of Crops—Crops grown for their leaves and stems need a relatively high proportion of nitrogen and potash as compared with phosphoric acid. Spinach, cabbage, and celery are good examples of this class. Lettuce needs a moderately heavy application of nitrogen, a large supply of available phosphorus, and a rather moderate or low quantity of potash, especially on peat lands. Crops grown for the ripe fruit, such as tomatoes and peppers, need a relatively high percentage of phosphoric acid in their fertilization, since much phosphorus is used in the development of mature fruit. Grains in general respond to the use of phosphoric acid (Figures 22 and 23).

The relative response of crops to the different fertilizer elements as worked out by Hartwell,[1] formerly of the Rhode Island experiment station follows:

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[1] B. L. Hartwell, "Jour. of the Amer. Soc. Agronomy," Vol. 13, p. 358. 1921.

TENTATIVE ARRANGEMENT OF CROPS IN ACCORDANCE WITH THEIR INCREASING RESPONSE TO FERTILIZER ELEMENTS; GROUP 3 GIVES GREATER RESPONSE THAN GROUP 1

Group	*Increasing nitrogen response*	*Increasing phosphorus response*	*Increasing potassium response*
	Rye	Carrot	Corn
	Bean	Buckwheat	Rye
	Corn	Millet	Cabbage
1	Cucumber	Oat	Turnip
	Cabbage	Pea	Bean
	Pea	Bean	Oat
	Potato	Tomato	Pea
	Wheat	Corn	Millet
	Sunflower	Potato	Wheat
	Turnip	Rye	Buckwheat
2	Tomato	Wheat	Carrot
	Beet	Sunflower	Potato
	Carrot	Barley	Tomato
	Oat	Lettuce	Barley
	Millet	Cabbage	Squash
	Parsnip	Beet	Sunflower
	Buckwheat	Cucumber	Beet
3	Lettuce	Onion	Onion
	Barley	Parsnip	Parsnip
	Squash	Squash	Lettuce
	Onion	Turnip	Cucumber

Use of Fertilizer Materials Separately—Superphosphate is the most widely used single material, which is applied alone or with manure. For grain and hay in a rotation of corn, small grain, clover, and timothy, with manure used on one of the crops,

FIGURE 22.—(*Upper*) POTATOES IN BLOOM, AROOSTOOK COUNTY, MAINE

Looking down the rows, which completely cover the space between them.

FIGURE 23.—(*Lower*) CABBAGE IN MASSACHUSETTS

On farm of Mr. George I. Stowe, West Milbury. (*Courtesy, American Agricultural Chemical Co.*).

the application of superphosphate is often the most economical fertilization. A little potash in addition is often profitable on very sandy soils, provided its cost is not too great. In the Middle West potash alone is often used to advantage for corn on muck or peat soils, or on so-called alkali spots. Nitrate of soda or nitrate of lime is widely used as a top-dressing on meadows, and as a side-dressing for celery and sometimes for onions to stimulate vegetative growth. Sulfate of ammonia and urea may serve the same purpose, especially during warm, growing weather, when soil bacteria are actively changing ammonia to nitrates. Tree fruits and grapes are rather generally fertilized with nitrogen, alone. Nitrate of soda, sulfate of ammonia, nitrate of lime, cyanamide, or urea may be used to advantage.

Quantity of Fertilizer to the Acre—The expected gross returns to the acre from a crop is the most important single factor in determining the rate of application of fertilizer. Little, if any, fertilizer can be used with profit on timothy that is worth but $4 to $8 an acre standing in the field unharvested. In those areas where hay is expensive, as when received from the country through a large terminal market such as New York, Boston, or Philadelphia, there is little doubt but that the use of nitrogen on timothy may yield handsome profits, but in the surplus hay-producing sections of New York, Pennsylvania, Ohio, or elsewhere, any commercial fertilizer put on directly for timothy is almost certain to result in financial loss. On the other

hand, with crop prices above average, 2000 to 3000 pounds of high-analysis fertilizer to the acre for seed potatoes may show highly satisfactory profits.

No general recommendation that will be safe for the farmer to follow can be given for a single crop like potatoes. Land prices, probable yields, distance from market, intensity of production, quality of seed used, and thoroughness of spraying, if any, are important determining factors. In the potato section of Maine and on Long Island, where good production methods are practiced, heavy fertilization (a ton or more of a moderately high-analysis fertilizer to the acre) pays well on the average. In contrast, on rather inaccessible cheap land where each farm grows but a few acres of table-stock potatoes and little attention is paid to quality of seed or control of disease and insect pests, 200 to 400 pounds of superphosphate to the acre along with manure or sod turned under may be the most economical fertilization, when the average yield and probable cash returns are given full consideration. Under exactly the same soil and climatic conditions, however, if high-quality, nearly disease-free seed is planted, and if good production methods are practiced, a ton of high-analysis fertilizer on each acre of potatoes grown for certified seed shows good profits on the average. When potatoes are thus fertilized, none is used on the other crops in a three-year rotation such as potatoes, oats or barley, and clover or a four-year rotation with timothy in addition as the fourth-year crop.

Rate of Use in Garden Fertilization—Gardens and lawns are frequently fertilized too heavily rather than too lightly. Fertilizer recommendations are usually made on the acre basis, which is sometimes difficult for the home gardener to interpret. Five hundred pounds of fertilizer to the acre is equivalent to but 1¼ pounds to 100 square feet, or 12½ pounds to 1000 square feet of lawn or garden. These quantities of fertilizer on 100 or 1000 square feet seem very small, yet they represent a fairly good application to the acre except in intensive gardening. For gardens 1500 to 2000 pounds of fertilizer to the acre properly applied is economical. Table XV shows the quantity of fertilizer for 1000 and 100 square feet that is equivalent to a given quantity to the acre.

TABLE XV—EQUIVALENT QUANTITIES OF FERTILIZER FOR AN ACRE, AND FOR 1000 AND 100 SQUARE FEET

	Rate of Application:	
to the acre	*to 1000 square feet*	*to 100 square feet*
pounds	*pounds*	*pounds*
100	2.50	0.25*
200	5.00	0.50
300	7.50	0.75
500	12.50	1.25
800	20.00	2.00
1000	25.00	2.50
1500	37.50	3.75
2000	50.00	5.00

* In order to avoid smaller fractions of a pound, an acre is considered as consisting of 400 instead of 435 areas of 100 square feet each. The above figures are sufficiently accurate for lawn and garden purposes.

Fertilization of Lawns—Some lawns like gardens are over-fertilized; others, curiously enough, are taken for granted and receive no fertilization. Two types of lawns may be considered; the straight grass lawn and the wild white clover-grass lawn. The two types require somewhat different treatment and management. For grass lawns, light fertilization is sufficient, if the clippings are left on the lawn, because only a small quantity of plant nutrients is removed from the soil in any one season. When, however, the clippings are removed, the equivalent of large crops is taken from the soil each season and feeding the lawn is essential for good results. On thrifty, well-established lawns the removal of the clippings is good practice.

For grass lawns two applications of fertilizer during the season are usually sufficient. The best time for the first application is in early spring immediately before growth begins. There is no danger of burning the sward at that season. Because the grass is dormant a larger application of fertilizer may be made safely at that time than during the active growing period. Early fall is a good time for the second application. The fertilizer used at either time for grass lawns should be relatively high in nitrogen. A mixture such as 10-6-4, 8-6-4, 6-9-4, or 5-10-5 is suitable. From 12 to 15 pounds to the 1000 square feet may be applied with a spreader or broadcast by hand on the lawn in early spring. Half of these quantities may be used in early fall. Whenever growing lawn grass is fertilized, the fertilizer

should be washed in by sprinkling liberally unless a fairly heavy shower follows immediately after the treatment.

For lawns that were liberally supplied with phosphorus and potash when they were established the application of nitrogen, alone, may be sufficient. In that event the use of 10 pounds of nitrate of soda or sulfate of ammonia to 1000 square feet of lawn applied during the cool growing weather of early spring and half that quantity in early fall is recommended. Wetting down thoroughly, on actively growing grass as already mentioned, is essential in order to avoid burning.

Wild white clover-grass lawns require somewhat different treatment from that outlined for grass lawns. It is best to remove all clippings from lawns which contain an appreciable proportion of wild white clover because leaving them on depresses the growth of the clover. Little, if any, nitrogen should be used on this type of lawn. Fertilization of such lawns is much simpler than that of grass lawns. The application of 10 pounds of 16- or 20-per-cent superphosphate, or its equivalent in other grades, and 2½ pounds of muriate of potash to 1000 square feet a year in late fall or early spring is sufficient. In fact, good results would follow the use of twice this application in alternate years, or even three times the amount every third year.

For grass lawns the superphosphate-potash treatment outlined for clover-grass lawns, in addition to straight nitrogen fertilization as outlined, should

keep grass lawns in a thrifty condition. The relation of liming to lawns is stated in Chapter IX.

METHODS OF APPLICATION

Several ways of applying fertilizer to cultivated crops are in general use. Among these are (1) applications in or alongside of the row, (2) broadcasting with a fertilizer or lime drill or by hand, the soil being uniformly covered with fertilizer, (3) top- or side-dressing, and (4) combinations such as part in the row and part broadcast, or one or both of these with top- or side-dressings after the crop is up and growing.

Row Application—Crops which have a smaller-than-average root system, or which are planted in rows a considerable distance apart, had best be fertilized in the row, especially if the rate of application is light, say 100 to 400 pounds to the acre. Three hundred to 400 pounds of fertilizer ordinarily produce a larger increase in yield of potatoes if applied in the row than if put on broadcast. The crop following potatoes, however, is benefited less by the residue from the potato fertilizer when it is applied in the row than when applied broadcast. The effect of fertilizer applications in the row is often noticed on grain following, the grain being much taller over, than between, the rows of the preceding crop; apparently plowing does not distribute such fertilizer to any marked extent. One hundred to 200 pounds of mixed fertilizer to the acre for corn

will probably produce a larger increase in yield if put on in the hill or row than if applied broadcast. The loss of soluble nitrogen from small broadcast applications made two to three weeks before the corn is large enough to begin using it may be a large proportion of the total nitrogen used.

If all crops in a rotation, or in a period of years as in truck gardening, are fertilized, the row is probably the best place for it. Long Island potatoes are grown regularly every year on the same land and are fertilized in the row, which is probably the best practice under these conditions. In-the-row applications are made with machinery. Corn and potato planters are typical, both being equipped with special attachments for distributing fertilizer while planting the seed. Extreme care is necessary in using heavy applications of fertilizers in the row or hill, in order to avoid loss in yield as a result of reduced germination which may be caused by actual contact between the seed and the fertilizer. However, if "concentrated" fertilizers are applied and mixed with the soil in the same thorough manner as is done with ordinary-strength fertilizers there is no additional hazard from the use of the more concentrated ones. Thorough mixing with the soil and avoiding direct contact between the fertilizer and the seed of sensitive crops are advisable with any soluble fertilizer.

Broadcast—Fertilizer for small grain is applied in the row, but since the rows are so close together such application may be considered as broadcast.

Some farmers apply 1500 to 2000 pounds of potato fertilizer with a lime spreader. Fertilizer for beans and other sensitive crops should be applied with a grain or fertilizer drill, all holes open, before planting, especially if considerable fertilizer is used. Beans and peas are particularly sensitive. Fertilizer, even superphosphate, in contact with the seed, reduces germination and consequently the stand and presumably the yield of beans. Such damage is more prevalent when the soil is dry than when it is in a normally moist condition. This damage to beans can be avoided by closing the opening so that no fertilizer is fed down into the bean row. With peas or other crops seeded with all drill holes open, it will be necessary to put the fertilizer on in advance of seeding, since there is danger of fertilizer damage to the seed (Figures 22 and 23).

Potatoes or cabbage grown with feed crops in a rotation, such as potatoes or cabbage, grain, clover, and timothy, may well receive all of the fertilizer for the entire rotation. Either crop will normally pay for the fertilizer used, and leave an ample residue for the other crops, yet there may be no fertilizer charge against the feed crops, since it may be borne by the cash crop. If upwards of 800 pounds to the acre are used for potatoes, one-half may well go on broadcast and the rest be applied in the row, when they are grown in a rotation with feed crops, such as corn, oats, clover, and timothy. Usually all of the fertilizer is applied broadcast for cabbage.

This method gives good results on the grain and forage crops following cabbage (Figure 24).

Side- or Top-dressing—Side-dressing celery with a soluble ammoniate is typical of this method of application. Nitrate of soda, nitrate of lime, leunasalpeter, urea, or sulfate of ammonia may be used in this way. Any of these ammoniates will be read-

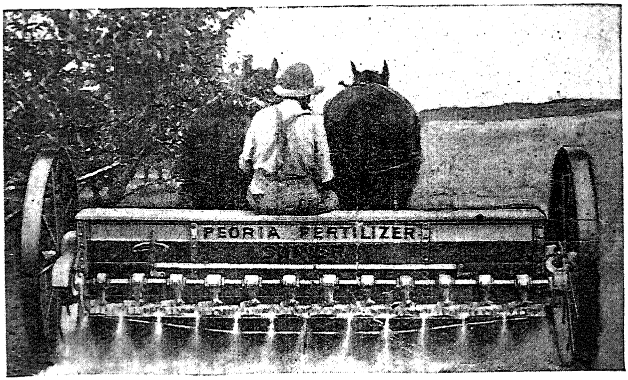

FIGURE 24.—FERTILIZER DRILL IN ACTION
(*Courtesy, Peoria Drill and Seeder Co.*).

ily available at the season when celery most needs nitrogen. There is no real reason for side-dressing or top-dressing a growing crop with a complete fertilizer or with potash salts, as some farmers are doing, because neither phosphoric acid nor potash are readily lost from the soil; consequently these should be applied before or at planting time. Considerable experimental evidence shows that all of the fertilizer, including nitrogen put on at seeding

time, gives as good results as if the fertilizer is put on in three or four different applications throughout the growing season. Much of the side-dressing must be done by hand and consequently is expensive. All of the fertilizer should be put on at one time, except where it is definitely known that later side-dressing with an ammoniate increases the yield or improves the quality sufficiently to show a good profit over and above the cost of the extra labor required. Putting nitrate on onions damaged by thrips is another example of side-dressing, but since the rows are so close together it may be just as well to regard the operation as top-dressing. Application of fertilizer to meadows, lawns, or pastures is an example of top-dressing.

IX

LIMING IN RELATION TO FERTILIZER PRACTICE

An intimate relationship exists between the use of fertilizers and applications of lime. If soils are rather sour, best results from fertilizers are not obtained until after lime has been used. On unlimed sour soils soluble phosphorus may be locked up with aluminum and iron in such a way as not to be of the greatest service to crops during the season in which the phosphorus is applied. It is for these reasons that liming materials and their use are considered here.

In Table XVI are given the yields which resulted from the application of lime and fertilizer on separate plots and from applying the same quantity of both lime and fertilizer together on the same plot. This experiment was conducted by the Ohio Agricultural Experiment Station. The data follow in Table XVI on the next page.

The marked effect of lime in addition to fertilizer on this soil is apparent from the data in Table XVI. The application of both lime and fertilizer on the same plot produced 6 bushels more corn, 300 pounds more clover, and 364 pounds more timothy hay to the acre than was produced on 2 plots one of

which was limed and the other fertilized. Moreover, the labor and rent or interest and taxes on the latter were essentially twice as much as on the land receiving both lime and fertilizer. This being true it was far more profitable to use both lime and fertilizer on the same soil than to use them separately on twice as much land.

TABLE XVI—EFFECT ON YIELDS WHEN LIME AND FERTILIZER WERE APPLIED, SEPARATELY AND TOGETHER, ON THE SAME LAND

	No fer'liz'r	*Lime*		*Fertilizer**		*Lime and fertilizer**		
Crop	*Yield*	*Yield*	*Gain over no lime*	*Yield*	*Gain over no fer'liz'r*	*Yield*	*Gain over no treatment*	*Gain together over lime and fer'liz'r separately on two plots*
	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels
Corn	11	26	15	26	15	47	36	6
Oats	25	39	14	42	17	45	20	—11
Wheat ...	6	15	9	18	12	26	20	—1
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Clover ...	594	1906	1312	1269	675	2881	2287	300
Timothy .	887	2961	2074	1316	429	3754	2867	364

* During the five-year rotation two tons of limestone, 300 pounds each of superphosphate (acid phosphate) and nitrate of soda, and 200 pounds of muriate of potash, to the acre, were applied as chemicals equivalent to 1000 pounds to the acre of a fertilizer containing 4.8 per cent each of nitrogen and of phosphoric acid, and 10 per cent potash, or to 200 pounds to the acre a year of a 5-5-10 fertilizer.

PURPOSE OF LIMING SOILS

Lime is used on soils to increase the yield or to improve the quality of crops. It is usually considered a soil amendment rather than a fertilizer. The term *lime* is used in its broad sense, including all soil-liming materials. Lime is generally used for the purpose

of correcting or counteracting what is called soil acidity, or for "sweetening" the soil. Another conception is that lime is used to satisfy the lime requirement of the soil. In some soils this correction of unfavorable conditions may be the rendering harmless of certain toxic or poisonous materials in the soil, such as soluble aluminum or organic substances.

As stated in Chapter I calcium is an essential plant-nutrient element. As nutrients calcium and magnesium are deficient in some soils. Under these conditions liming materials supply calcium and magnesium which are used as nutrients by the crop. Thus liming materials actually may serve as a fertilizer rather than as a soil amendment. In general, however, liming materials are used for the purpose of correcting excessive soil acidity. Another point worthy of consideration is that in enabling legumes to grow vigorously lime produces indirect effects similar to those of nitrogenous fertilization.

LIMING MATERIALS

There is a large group of different materials used on the soil for the definite purpose of satisfying its lime requirement. These may be classified as *carbonates,* including limestones, shells, and marl, *caustic limes,* burned and hydrated, and a *by-product,* blast furnace slag.

Carbonates—*Limestone*—Limestones are ground to various degrees of fineness for soil use. In the

East, where freight, truck, and wagon hauls are often long and difficult, it is important that the stone be fine enough to give quick action in the soil. To serve this purpose satisfactorily, 50 per cent should pass through a 100-mesh sieve,* and about 90 per cent of it should pass through a 20-mesh sieve. In addition to composition fineness is the most important consideration in the value of limestone for use on the soil.

Because of considerable expense of quarrying, grinding, hauling, and spreading, a limestone to be really economical for soil use should contain at least 90, and preferably more than 95, per cent of total carbonates, that is, of calcium and magnesium combined.

Limestones in general contain both calcium and magnesium carbonates. Those having but little magnesium are called high-calcium stones; those with much magnesium are called dolomitic or high-magnesium stones. On some soils magnesium is needed as a plant nutrient. Theoretically magnesium carbonate corrects more acidity than does calcium carbonate, but in the field it is very difficult to note any real difference. Some have objected to magnesium in liming materials, but there does not seem to be any really good basis for such objections. On the other hand, there seems to be no real reason for assigning a higher value to magnesium than to calcium in limestones. The sum of the calcium carbonate and the magnesium carbonate, or the

* U.S. Bureau of Standards sizes.

total carbonate content, therefore, is regarded as the proper method of evaluating limestones for soil use.

Oyster Shells—Clean oyster shells contain about 90 to 95 per cent of calcium carbonate. When finely ground they are a very satisfactory liming material.

Marl—Marl which was formed in water occurs in ponds or lakes and sometimes in the bed of sluggish streams. It has been formed from snail shells and from the plant chara, which has the power of taking lime out of the water in which it grows. When the plant decays, the lime settles to the bottom of the water. Owing to its mode of formation, marl is mixed with in-washed soil material in varying proportions. Marl for soil use should have at least from 75 to 80 per cent of carbonates, even for short hauls. Where it must be transported by freight and later by wagon or truck, it should be equal to good limestone containing from 90 to 95 per cent of carbonates. Its use is usually restricted to the wagon- or truck-haul area about the deposit.

Caustic Limes—*Quick or Burned Lime*—Burned lime is made by burning limestone which, chemically, is calcium carbonate ($CaCO_3$). During burning carbon dioxide (CO_2) is driven off, leaving calcium oxide (CaO), quicklime. $CaCO_3 - CO_2 = CaO$. One hundred pounds of pure calcium carbonate on burning loses 44 pounds of carbon dioxide, leaving 56 pounds of calcium oxide or

quicklime. Thus 56 pounds of pure quicklime is equivalent in neutralizing power to the calcium oxide in 100 pounds of pure calcium carbonate.

Hydrated Lime—Hydrated lime is formed by adding water or steam to quicklime. Calcium oxide unites with water to form calcium hydroxide, commonly called "hydrate" or "hydrated lime." ($CaO + H_2O = Ca(OH)_2$). In this process 18 pounds of water combine with 56 pounds of quicklime, making 74 pounds of hydrated lime, equal in calcium-oxide content to 100 pounds of pure calcium carbonate.

Both calcium oxide and hydroxide take up carbon dioxide, or air-slake, when exposed to the air. In other words, they go back to the original carbonate form. Thus the oxide, (CaO), + carbon dioxide, (CO_2), gives calcium carbonate, ($CaCO_3$), and the hydroxide ($Ca(OH)_2$) + carbon dioxide (CO_2) gives calcium carbonate ($CaCO_3$) + water (H_2O).

By-product—*Blast Furnace Slag*—Blast furnace slag is a by-product of the manufacture of pig iron from iron ore and limestone. During burning, silica from the ore unites with calcium from the limestone to form calcium silicate. Carbon dioxide is driven off by heating the same as in making burned lime. There is, however, a very small percentage of quicklime in the slag. For soil use slag, which is a glassy material, should be ground even finer than limestones which are in general more or less porous.

PUBLIC CONTROL OF THE COMPOSITION OF LIMING MATERIALS

The provisions of the New York Fertilizer and Lime Law are stated on page 95. Sections 4d, e, and f cover liming materials and show the requirements of the law. This is relatively typical of the various state lime control laws.

SPEED OF ACTION IN THE SOIL

There is a vast difference in the speed of action in the soil of the different liming materials. The caustic forms of lime act more quickly than do the carbonate or silicate forms if all are mixed with the soil to the same extent. Their relative speed of action, quickest listed first, is as follows:

Burned or quick lime.
Hydrate or hydroxide.
Limestone (finely ground).
Blast furnace slag.

Burned or hydrated lime may correct acidity in a very few days; on the other hand limestone and slag require several months if the lime requirement of the soil is rather high. For best results any form of lime should be mixed with the soil very thoroughly. Surface application of soluble fertilizers gives good results, but even quick lime acts rapidly only when in intimate contact with the soil particles.

MEASUREMENT OF ACIDITY OR LIME REQUIREMENT

Rain water carries acid into the soil, the decay of organic matter in the soil produces acids, and most crops use nitrogen in a form that tends to produce soil acidity. The combined result of the action of these acids is a reduction of the lime and other bases in the soil. Most humid soils originally contained only moderate quantities of limestone and much of that native supply has been lost from many soils. In fact most of the soils east of the Great Plains are now acid in character, although local areas, of course, contain limestone, and others are but slightly acid.

Soil acidity is measured in pH units. At a pH of 7.0 a soil is neutral; that is, the acid and the alkaline materials are of equal strength and consequently neutralize each other completely. A soil having a pH of 6.5, 5.5, and lower is acid. On the other hand one having a pH of 7.5 and higher is alkaline. While plants thrive over a considerable range of pH the best or optimum pH varies greatly with different plants, some doing best above pH 7.0 and others below pH 5.0.

Relative acidity and alkalinity of soils having different pH values may be stated as follows:

Soil Reaction	*pH*
Very strongly acid	4.0 or lower
Strongly acid	4.5 to 5.0
Medium strongly acid	5.0 to 5.5
Moderately acid	5.5 to 6.0

(*Continued on next page*)

Slightly acid	6.0 to 7.0
Neutral	7.0
Slightly alkaline	7.0 to 7.5
Strongly alkaline	7.50 and higher

Fertilizers affect the pH of soils (page 88). Some make it lower or more acid and others raise it or make the soil less acid or more alkaline. Lime, however, is the principal material used for reducing the acidity or increasing the alkalinity of soils. In this connection the term *lime requirement* has developed. Lime requirement is expressed as the quantity of an agricultural liming material required to produce thrifty growth of a given crop on a particular soil. It may be expressed in terms of a finely ground limestone, of a hydrated lime, or of any other form in use.

USE OF LIME

There is wide variation in need for lime of different crops on the same soil. Some crops are lime-loving or very sensitive to acidity; others may be indifferent to lime and still others are tolerant of high acidity. If a sensitive crop like cauliflower is to be grown on a rather sour soil, it is advisable to use a quick-acting form such as burned or hydrated lime. This is particularly necessary when it has been impossible to put on and mix a slow-acting form of lime with the soil the year before planting this crop. Where possible, this is the more economical way of growing this crop. For crops that give a high cash return to the acre, the quick and

more expensive forms may generally be used with profit. Usually, however, for crops like clover, sweet clover, and alfalfa, it is necessary to begin liming long enough in advance of seeding to correct acidity sufficiently with the slower-acting, cheaper forms, such as limestone or slag.

RESPONSE OF CROPS TO LIMING

There is wide variation in the response of crops to liming or to a deficiency of it in the soil. The field crops that are more sensitive to acidity are at the top of the first list. The relative response of crops to liming follows:

FIELD CROPS

Legumes	*Grains*	*Grasses*
Alfalfa	Barley	Kentucky blue grass
Sweet clover	Corn	Timothy
Red clover	Wheat	Canada blue grass
Alsike	Oats	Redtop
Soybeans	Buckwheat	Rhode Island bent grass
White clover	Rye	
Cowpeas		
Vetch		
Lespedeza		

VEGETABLE[1]

1, None	2, Slight	3, Moderate	4, Marked
Beans (field)	Sweet corn	Cauliflower	Lettuce
Beans (lima)	Carrot, pea	Cabbage	Beets
Beans (snap)	Bean (pole)	Eggplant	Celery

(*Continued on next page*)

1, None	2, Slight	3, Moderate	4, Marked
Potato	Brussels sprouts	Chard	Parsnips
Tomato	Cucumbers	Chinese cabbage	Spinach
Radish	Endive, Kale	Broccoli	Asparagus
Turnip	Collards	Muskmelon	Okra
Rutabaga	Dandelion	Mustard	Pepper
Cress	Kohl-rabi	Martynia	Onions
Chicory	Pumpkin		Leek
Watermelon*	Rhubarb		Salsify
	Squash		
	Horseradish		

[1] Hartwell, B. L., and co-workers. Rhode Island Experiment Station.
* Watermelon yield was materially reduced by liming.

Crops in group 1 ordinarily do not respond to liming on soils of moderate acidity. Those in group 2 respond slightly, and the yields of those in group 3 are increased moderately, and those in group 4 are markedly increased on moderately acid soils. Most vegetables thrive on slightly acid soils.

Soils vary widely in acidity and crops differ so greatly in their need of lime that one cannot suggest definite amounts to apply. A sensitive crop such as alfalfa needs up to three tons, and sometimes more, of finely ground limestone to the acre for good growth on very sour soils.

Some plants require distinctly acid soils. Among them are many ornamental shrubs and perennial flowers. Many evergreens seem to thrive better on acid soils than on soils which contain much limestone. The white cedar (*Thuja occidentalis*) is an exception, at least, it thrives on limestone soils.

Among the broad-leaf evergreens mountain laurel *(Kalmia)*, rhododendron, and sand myrtle *(Leiophyllum)* thrive best in acid soils.

Deciduous shrubs which do best on acid soils include azaleas, blueberry *(Vaccinium)*, chokeberry (*Aronia*), flowering dogwood (*Cornus florida*), heather *(Calluna, Erica)*, huckleberry *(Gaylussacia)*, shadblow (*Amelanchier*), trailing arbutus *(Epigaea)*, and rhodora *(Rhodara canadensis)*.

Some hardy perennials seem to prefer acid soils. Examples are bluets (*Hustonia*), some lilies, and mountain phlox (*Phlox ovata*).

Generally speaking it is easier to reduce acidity by liming than it is to change an alkaline soil to an acid one, or to make a soil more acid, in order to grow the plants which seem unable to tolerate alkalinity or mild acidity. Acid-forming organic matter helps to increase acidity. Aluminum sulfate and iron sulfate have been used with fair success for increasing soil acidity.

The quantities of aluminum sulfate required to make certain changes in the pH of soils is given in Table XVII.

TABLE XVII—QUANTITIES OF ALUMINUM SULFATE REQUIRED TO CHANGE THE pH OF SOILS [2]

Acidity of Soil	*pH*	*Aluminum sulfate pounds per square yard*
Medium acid	5.5 to 6.0	¼
Slightly acid	6.5 to 7.0	½
Neutral to strongly acid	7.0 to 8.0	¾

[2] Fertilizer Recommendations for New York. Bull. 281, 1939.

Care is required in the use of aluminum sulfate. It should be well distributed over the soil and not too much of it used very close to the plants. The aluminum sulfate should be watered into the soil unless it is applied at a time when rain may be depended on to dissolve it and carry it into the soil. The effect of aluminum sulfate disappears with the passing of time. It is, therefore, necessary to check the pH after a time and apply more as may be required. The application of organic matter to bring about acidity or of using natural soil of the desired acidity may be a simpler and a more satisfactory procedure.

LIME IN RELATION TO LAWNS

Kentucky blue grass *(Poa pratensis)* is usually regarded as thriving on soils of moderate acidity, but it does grow fairly well on soils of somewhat higher acidity. Some of the bent grasses (*Agrostis*) thrive on medium strongly acid soils. Heavy fertilization and the incorporation of organic matter probably enable plants in general to make reasonably good growth on soils which are normally of too high acidity for them.

Lime may be used to bring acid soils to the proper reaction for most plants that tolerate some acidity. Soils vary in the quantity of lime that is required to bring about a given change in pH. Light sandy soils require relatively small applications of lime to change their pH. Heavy soils, on the other hand,

require relatively large quantities of lime to effect similar changes in their pH.

Sprague [3] has worked out the quantities of hydrated lime required to change the pH of soils ranging from light sandy to clay loam soils. These figures are given in Table XVIII.

TABLE XVIII—POUNDS OF HYDRATED LIME REQUIRED TO CORRECT SOIL ACIDITY *

Soil acidity expressed in pH values	*Lime Per 1000 Square Feet*			
	Light sandy soils	*Medium sandy loam soils*	*Loam and silt loam soils*	*Clay loam soils*
pH 4.0	60 lbs.	80 lbs.	115 lbs.	145 lbs.
pH 4.5	55 lbs.	75 lbs.	105 lbs.	135 lbs.
pH 5.0	45 lbs.	60 lbs.	85 lbs.	100 lbs.
pH 5.5	35 lbs.	45 lbs.	65 lbs.	80 lbs.
pH 6.0	None	None	None	None

* About one and one-half times these quantities of finely ground limestone are required to bring about the above changes in pH values.

APPLICATION OF LIME

Lime may be applied in a number of ways: by hand with a shovel, with the fertilizer distributor of a grain drill, or with a lime or fertilizer sower.

By Hand—The earlier lime applications were all made by hand with a shovel. It is impossible, however, to distribute light applications of lime in this way with a satisfactory degree of uniformity for best results. Furthermore, it is hard, dusty work. The dust from the caustic limes is very disagreeable to

[3] Sprague, H. B., Liming Lawn Soils. Cir. 362, New Jersey Agr. Exp. Sta. p. 4. 1936.

both man and horses. Hand spreading, therefore, is not a popular method.

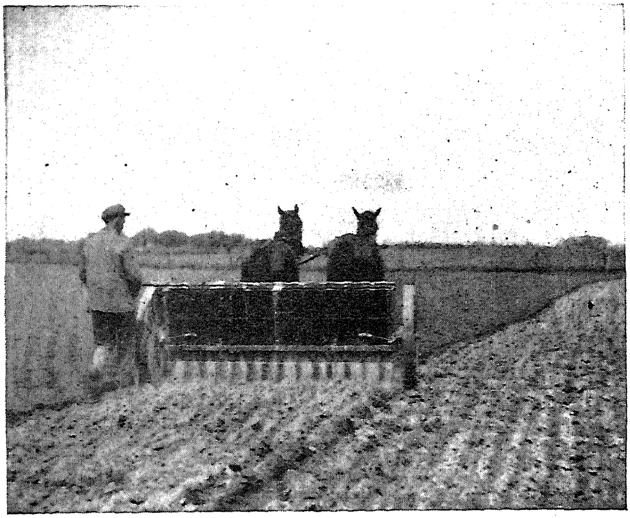

FIGURE 25.—BROADCAST LIME AND FERTILIZER SPREADER

Spreading limestone in New York. (*Courtesy, R. F. Pollard*).

With Grain Drill—Light applications, consisting of a few hundred pounds to the acre, especially the caustic limes, may well be made with a grain drill. The grain drill holds down dust better than any other method.

With a Lime or Fertilizer Sower—The lime sower or spreader which is made for this definite purpose is the best means of spreading lime. Machine application is uniform, and may be made at

a rate that is either light or heavy. The rate may be varied from a few hundred pounds to several tons to the acre. This method is most rapid and, therefore, most economical of labor (Figure 25).

In Table XIX are given the factors for the conversion of the percentage composition of one form of lime into the percentage as expressed in another form.

TABLE XIX—CONVERSION FACTORS FOR LIMING MATERIALS

Given, per cent as	*To find per cent as*	*Multiply by*
Calcium oxide, CaO	Calcium carbonate, $CaCO_3$	1.784
Calcium carbonate, $CaCO_3$	Calcium oxide, CaO	0.560
Calcium hydroxide, $Ca(OH)_2$	Calcium oxide, CaO	0.757
Magnesium oxide, MgO	Magnesium carbonate, $MgCO_3$	2.091
Magnesium carbonate, $MgCO_3$	Magnesium oxide, MgO	0.478
Magnesium hydrate, $Mg(OH)_2$	Magnesium oxide, MgO	0.691
Magnesium carbonate, $MgCO_3$	Calcium oxide, CaO equivalent	0.664
Magnesium hydroxide, $Mg(OH)_2$	Calcium oxide, CaO equivalent	0.960
Magnesium oxide, MgO	Calcium oxide, CaO equivalent	1.390
Magnesium carbonate, $MgCO_3$	Calcium carbonate $CaCO_3$ equivalent	1.186

X

ORGANIC MATTER IN RELATION TO FERTILIZER PRACTICE AND USE

THE relation of soil organic matter to fertilizer practice is purposely treated briefly. The main points are stated in essentially outline form.

In its broadest sense the term *organic matter* includes all materials in the soil of either plant or animal origin. The term *humus* is held to apply to organic materials regardless of their origin which have reached such an advanced stage of decomposition as to be almost inert. Such organic matter is inactive except that it tends to impart dark color to soils and that it improves the physical condition of the soil. It is the fresh or active organic matter, in the main, with which the following pages deal.

EFFECTS OF ORGANIC MATTER ON SOILS

Organic matter is beneficial to soils in many ways. In stating them it is not feasible to distinguish between those benefits which are derived directly from the addition of fresh organic matter to the soil and those derived from the humus in the soil. Fertilizers cannot have their full beneficial

effects on crop yields if the soil is too low in active organic matter.

In soils of medium to heavy texture organic matter tends to bring about a grouping or granulation of the soil particles. Granular soils are less tenacious and work more easily than do puddled ones. In light soils, such as sandy loams and sands, on the other hand, organic matter holds the soil particles together and thus improves conditions for plant growth. Moreover, this reduces wind movement and erosion of such soils.

Organic matter in the soil takes up and holds water in much the same way as a sponge does. Sandy soils in particular are benefited in this manner. In experimental work done some years ago the writer added organic matter to a sand. Approximately four per cent of organic matter added to sand increased its water-holding capacity to the extent of forty per cent.

By granulating a soil it is enabled to absorb rainfall more rapidly than before. This reduces the loss of rainwater as runoff and in so doing, organic matter tends to reduce the loss of surface soil by erosion. Moreover, the soil granules are less easily moved by runoff water than are the tiny individual soil particles. Thus granulation tends to check erosion.

LOSSES OF ORGANIC MATTER FROM SOILS

Soils vary widely in their content of organic matter, from one per cent, or even less, to 5 or 6 per

cent in moderately well-drained soils. These percentages correspond with from 10 to 60 tons of organic matter in the top seven inches of soil.

Organic matter serves largely as the food of soil bacteria and is lost from soils by the process of decay that is brought about by soil bacteria. During decay nitrogen is liberated from the organic matter in a form which plants can use in their growth. Wheat requires 2 pounds of nitrogen for the production of a bushel of grain. A 25-bushel crop, therefore, requires 50 pounds of nitrogen for the production of the grain and considerably more for the straw. In other words if no fertilizer nitrogen is used for wheat, between 600 and 1000 pounds of soil organic matter must decay and disappear from the soil in order to produce a crop of wheat. In growing, the wheat produces organic matter as roots and stubble which remains in and on the soil. Some losses of organic matter take place during the production of crops. It is essential to maintain a revolving supply of active organic matter in the soil.

Field and forest fires are another cause of tremendous losses of organic matter every year. Moreover, organic matter is lighter than soil and consequently floats readily and is lost in runoff water. Additional organic matter is lost out of the soil by direct soil erosion. Completely decomposed or humic organic matter is lost by leaching in the drainage from sour soils.

MAINTENANCE OF THE ORGANIC MATTER AND NITROGEN SUPPLY IN THE SOIL

The maintenance of a moderately good supply of active organic matter in the soil of the average farm is a difficult problem. On the vegetable farm where a large share of the soil is growing vegetables every year this problem is most difficult. The shortage of organic matter and the nitrogen it contains is the limiting factor in crop production on many eastern and southern farms. Moreover, the same situation is rapidly overtaking corn- and wheat-belt farms of the Midwest, West, and Southwest.

No adequate supply of purchasable organic matter exists. A few farmers, fruit growers, and market gardeners may buy feed or manure from neighbors. In general farming, however, organic matter must be produced on the farm if, indeed, not on each field or lot. A number of things can be done economically by the individual land operator for the purpose of returning organic matter to the soil or of producing it on the land.

Addition of Lime—Many soils have become so sour that clover and other legumes no longer thrive. On such soils the first step in producing legumes and of obtaining the benefits of the nitrogen which legumes may fix in the soil is the application of sufficient lime for the production of legumes.

Applications of Phosphorus—Legumes in general require goodly supplies of phosphorus and con-

sequently are unable to make satisfactory growth on many soils in this country, particularly in the East and Southeast. In order to obtain the production desired, clover, alfalfa, peas, soybeans, cowpeas, lespedeza, beans, peanuts, and crotolaria require moderately liberal applications of phosphorus. It is because of the ability of the legumes to fix nitrogen that good yields of legumes are so important.

Crop Residues—Moreover, crops in general make a much larger root growth and leave relatively large quantities of residues in and on the soil when the main crop is amply fertilized with phosphorus, and with nitrogen and potash as well, if they are required. One real advantage of crop residues for the purpose of adding organic matter to the soil is that the roots and stubble are uniformly distributed over and throughout the soil. Such materials as corn and cotton stalks, potato vines, stubble from grain and hay crops, and the remains from vegetables are typical crop residues.

Barnyard Manure—Barnyard manure is one of the most valuable by-products of the dairy and general livestock farm. Sufficient manure cannot be produced, however, from the crops regularly grown on the farm to keep up the organic content of the soil. This is owing to the fact that farm animals in the processes of digestion destroy between one-third and one-half of the organic matter in the feed consumed. Moreover, much additional loss of organic matter occurs between the time manure is produced

and the time of its incorporation with the soil. Such losses need to be reduced by spreading manure on the soil as soon as possible after it is made. Best results from the use of manure on feed crops, are usually obtained from light, frequent applications.

Rotation of Crops—Rotation of crops is the growing of intertilled crops, grains, grasses, and legumes in regular order. Greater losses of organic matter take place under intertilled crops such as corn, potatoes, and vegetables than under grain or hay. Legumes aid in building up the supply of nitrogen and organic matter in the soil.

Green Manures—Green-manure crops are those which are grown for the specific purpose of being turned under in the green state for soil improvement. These crops may be used to best advantage in those sections which have a growing season long enough to admit of considerable growth of a green-manure crop either before the main crop is planted or after it has been harvested. Green-manure and catch and cover crops are especially useful in the South.

It is often desirable to use legumes as green manures, especially in cropping systems which are not manured or fertilized heavily. Non-legume green manures are especially useful after heavily fertilized crops for taking up and holding plant nutrients against loss by leaching.

Among the annual legumes which are most useful in the central and northern parts of the United States are vetch, Canada pea, cowpea, and soybean,

and to the southward velvet bean, crimson clover, peanut, lespedeza, and in the deep Southeast crotolaria in addition. Vetch is used over a wide north-south range. Useful biennial legumes are red, alsike, and sweet clover. Desirable non-legumes are rye, oats, wheat, mustard, buckwheat, timothy, millet, sudan grass, rape, and turnips. Rye and wheat in particular should be turned under soon after heading out or even earlier. In general green-manure material gives best results if plowed under at least ten days to two weeks before the main crop is planted.

INDEX

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